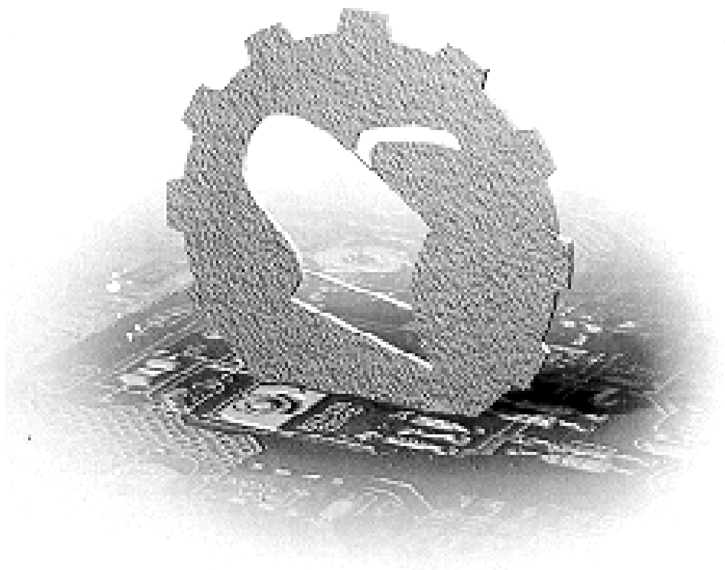
Print ISSN 0554-5587
On line eISSN 2406-1123
UDK 631 (059)

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 XLIII, Број 1, 2018.
Year XLIII, No. 1, 2018.

ПОЉОПРИВРЕДНА ТЕХНИКА

НАУЧНИ ЧАСОПИС

AGRICULTURAL ENGINEERING

SCIENTIFIC JOURNAL

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

WEB адреса ***(WEB Address)***
www.jageng.agrif.bg.ac.rs

Техничка припрема *(Technical editor)*
Доцент др Коста Глигоревић, Пољопривредни факултет , 11080 Земун-Београд

Лектура и коректура: *(Proofreader)*
Проф. др Иван Златановић, Пољопривредни факултет , 11080 Земун-Београд

Превод: *(Translation)*
Проф. др Иван Златановић, Пољопривредни факултет , 11080 Земун-Београд

Штампа *(Printed by)*
Пољопривредни факултет , 11080 Земун-Београд
Часопис излази четири пута годишње

Тираж *(Circulation)*
350 примерака
Дистрибуција примерака часописа Пољопривредна техника за заинтересоване је бесплатна .

Радови објављени у часопису индексирани су у базама *(Abstracting and Indexing)*:
AGRIS (International Information System for the Agricultural Science and Technology)
SCIndeks (Serbian Citation Index)
NAAS (National Academy of Agricultural Sciences - India)
ScienceMediaCentre
ArgosBiotech
CiteFactor (International Academic Scientific Journals)
J4F (Journals for Free).

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

На основу мишљења Министарства за науку и технологију Републике Србије према решењу бр. 413-00-606/96-01 од 24. 12. 1996. године, часопис Пољопривредна техника је ослобођен плаћања пореза на промет робе на мало.

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 XLIII
Broj 1, 2018.
Strane: 1 – 11

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XLIII
No 1, 2018.
pp: 1 – 11

UDK: 611.792. *Review article*

APPLICATION OF ANAEROBIC ADHESIVES AT MACHINERY REPAIR

Vladimir Bashkirtsev[1] , Yury Kuznetsov[*2], Larisa Kalashnikova[3]

[1]*Russian Engineering Academy of Management and Agribusiness*, Settlement *"Chelyuskinsky" Moscow Region, Russian Federation*
[2]*Orel State Agrarian University named after N.V. Parakhin, Orel, Russian Federation*
[3]*Orel State University named after I.S. Turgenev, Orel, Russian Federation*

Abstract: The importance of application of anaerobic adhesives during maintenance and repair works is illustrated. The comparative processing characteristics of anaerobic compositions and recommendations on adequate choice of adhesive material trademark are presented. We suggest the conventional technologies of operating capacity restoration of joints and assemblies that lost their performance when in operation with anaerobic adhesives application.

Key words*: adhesive, anaerobic composition, polymer, repair, restoration, hermetization, fixation, clearance gap.*

INTRODUCTION

At long-term operation of agricultural machinery of different purpose at the places of metal stress concentration, fatigue cracks can appear [1, 2, 3]. As an example, the crack is presented in figure 1 (a) near the central cylinder head bolt of the internal combustion engine. It connects the cooling system cavity and unit head oil duct. This is one of the reasons of getting of engine oil into the engine cooling system. No one of the existing conventional repair technologies with applied welding method is not suitable to fill-in such kind of crack. The repair and technical enterprises experience testifies that such a unit is usually rejected.

[*] Corresponding author. E-mail: kentury@rambler.ru

The usage of polymer materials allows unit performance restoration with the above mentioned defect without dismounting the engine and its complete disassembly. For conducting repair operations, it is reasonable to apply anaerobic adhesives among polymer materials [4, 5]. Anaerobic adhesives are special liquor mixtures of different viscosity. Name "anaerobic" is taken from biological terminology, where it was applied to microorganisms existing without oxygen. "Anaerobic" means that adhesive material can remain in initial state without its property change for a long time and harden quickly forming solid polymer layer in narrow clearances between surfaces at temperatures 15-35^0C in the conditions of terminating the aerial oxygen contact [6].

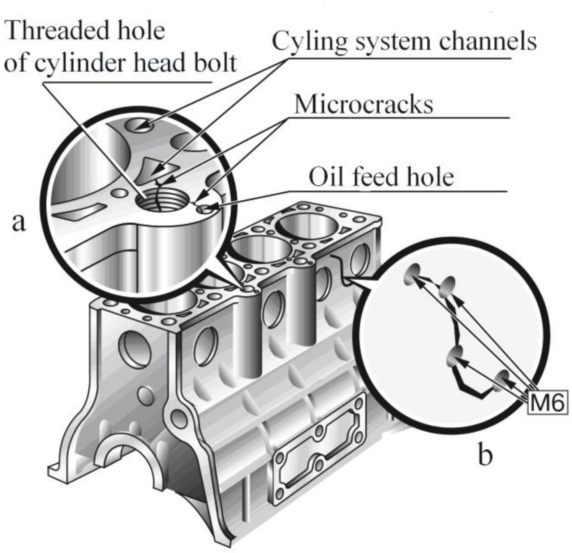


Figure 1. Hermetization of microcracks in engine cylinder block

It should be emphasized, that anaerobic adhesives can be used not only at cracks hermetization. In addition, they can be in demand to fix the tread, rolling bearing fit restoration and can be used as liquid gaskets etc. [4, 7].

Anaerobic composition base is capable for polymerization compounds of acrylic variety, for example, dimethacrylic ester of polyalkyleneglycols. Anaerobic composition consists of inhibitive and initiators providing its long-term storage and rapid curing in clearances and thickeners, modifiers, colorants and other additives, etc. All anaerobic adhesives trademarks are one-component materials.

The advantages of anaerobic adhesives are the following [4, 5, 6]:

- high rate of hardening, (fixation duration is 15-30 min);
- high viscosity, it allows clearance tightening up to 3 mm (except for saturating compositions);
- feature stability at long-term operation in conditions of thermal shock and elevated vibration;
- high strength properties (hardness at impact shift is 8-20 kJ/m^2; ultimate share stress – 20-30 MPa).

Among the main disadvantages of anaerobic compositions, it is possible to differentiate the following:

- low strength at bonding greasy surfaces (ultimate share stress – 0,5-5 MPa);
- dependence of strength properties of hardened adhesive from the clearance between associable surfaces.

The technology of anaerobic adhesive application is sufficiently simple and universal. While performing repair operations these operation is done manually applying adhesive from standard bottle, with special nozzle.

The right choice of adhesive material trademark, technology compliance of adhesive composition application is of significant importance.

MATERIAL AND METHODS

For the purpose of reasonable choice of anaerobic adhesive trademark while performing maintenance and repair works of different joints, the following anaerobic compositions were analyzed: АН-1У (Russia), Уг-7 (Russia), Анатерм-6к (Russia), Анатерм-111 (Russia), Permatex® Bearing Mount for Close Fits (USA), Permatex® Bearing mount for Worn (USA).

RESULTS AND DISCUSSION

While selecting anaerobic adhesive trademark it is necessary to take into consideration the operation conditions of the repaired object: its loading mode, temperature mode, clearance between joint surfaces, and surface cleaning quality, coating nature, etc.

One more important parameter is abrasive viscosity. Its choice should be based on clearance between assembled parts (table 1).

Comparative characteristics of some the most commonly used anaerobic adhesives of Russia and the USA production are presented in table 2 [6].

According to strength properties, anaerobic polymer materials are divided into high- middle- and low-strength. After hardening anaerobic materials possess high thermal and chemical resistance, maintain operability of joints and parts at their operation in contact with organic solvents and aggressive media in broad range of temperatures and pressures. The rate of hardening and duration of achievement of maximum strength of connections with anaerobic adhesives depend on ambient temperature. For example, at temperature below 15 ^{0}C polymerization is slowing down. High penetrating capacity of anaerobic adhesives provides heavy coverage of cracks, microdefects of welded joints and clearances.

It is necessary to stress that anaerobic composition-hardening rate is influenced with contacting material. According to this feature, contacting materials can be divided into three groups:

- active – accelerating polymer hardening (cuprum alloys, nickel, low-carbon steels);
- normal – not influencing hardening rate (ferrum, carbon steels, zinc);

- passive – slowing down hardening (high-carbon steels, aluminum, gold, titanium and its alloys, materials with anticorrosion coatings, plastic articles).

On the open surfaces, anaerobic adhesives can remain liquid for an indefinite time and they are easily removed including water-cleaning solutions.

Table 1. Selection of anaerobic adhesive viscosity depending on tightened clearance

Clearance, mm	up to 0,07	up to 0,15	up to 0,25	up to 0,35	up to 0,60
Adhesive viscosity, MPa·s	5-20	100-150	500-800	$(1\text{-}3)\cdot 10^3$	$(5\text{-}35)\cdot 10^3$

Table 2. Technological characteristics of some anaerobic adhesives of Russia and the USA production [6]

Trademark	Color	Tightened clearance, not more than (thread diameter)	Operating temperature range, ^0C	Producer
Compositions for infirm fixation of thread				
Анатерм-17	blue	0,35 mm	-60…+150	Federal State Unitary Enterprise «Research Institute of Polymers»
Унигерм-2М	green	0,15 mm	-60…+150	Federal State Unitary Enterprise «Research Institute of Polymers»
Low Strength Thread lockers	purple	no more M6	-54…+149	Permatex (USA)
Анагерм-100	green	0,3 mm	-60…+150	LLC «TECHNO-BASIS»
Анагерм-120	green	0,45 mm	-60…+150	LLC «TECHNO-BASIS»
Compositions for middle fixation of thread				
MediumStrength Threadlockers	blue	M6…M20	-54…+149	Permatex (USA)
Анатерм-18	blue	0,4 mm	-60…+100	Federal State Enterprise «Research Institute of Polymers»

Унигерм-6	*red*	*0,3 mm*	*-60…+150*	*Federal State Unitary Enterprise «Research Institute of Polymers»*
Анагерм-101	*green*	*0,3 mm*	*-60…+150*	*LLC «TECHNO-BASIS»*
LOCTITE-243	*blue*	*>M36*	*-55…+150*	*LOCTITE*
Compositions for firm fixation of thread				
Анагерм-102	*blue*	*0,3 mm*	*-60…+150*	*LLC «TECHNO-BASIS»*
High Strength Thread locker	*red*	*M10…M20*	*-54…+149*	*Permatex (USA)*
Анатерм-111	*green*	*0,4 mm*	*-60…+150*	*Federal State Unitary Enterprise «Research Institute of Polymers»*
Унигерм-9	*green*	*0,3 mm*	*-60…+150*	*Federal State Unitary Enterprise «Research Institute of Polymers»*
LOCTITE-270	*green*	*>M20*	*-55…+150*	*LOCTITE*
Compositions for fixation of bearings, bushes				
LOCTITE-603	*green*	*0,15 mm*	*-50…+150*	*LOCTITE*
LOCTITE-638	*green*	*0,25 mm*	*-50…+150*	*LOCTITE*
Bearing mount for Close Fits	*green*	*0,18 mm*	*-50…+204*	*Permatex (USA)*
Bearing Mount for Worn Parts	*silver*	*0,5 mm*	*-54…+149*	*Permatex (USA)*
Анагерм-103ВТ	*orange*	*0,3 mm*	*до +250*	*LLC «TECHNO-BASIS»*
Анагерм-103	*red*	*0,4 mm*	*-60…+150*	*LLC «TECHNO-BASIS»*
Анатерм-6К	*red*	*0,45 mm*	*-60…+150*	*Federal State Unitary Enterprise «Research Institute of Polymers»*

Анатерм-111	*green*	*0,4 mm*	*-60…+150*	*Federal State Unitary Enterprise «Research Institute of Polymers»*
Compositions for microcracks hermetization				
Анагерм-112	*blue*	*0,05 mm*	*до +150*	*LLC «TECHNO-BASIS»*
Анатерм-1у	*red*	*0,1 mm*	*-50…+150*	*Federal State Unitary Enterprise «Research Institute of Polymers»*
Унигерм-7	*green*	*0,2 mm*	*-50…+150*	*Federal State Unitary Enterprise «Research Institute of Polymers»*
Encapsulating compositions (liquid gaskets)				
Анагерм-130	*green*	*0,6 mm*	*-60…+150*	*LLC «TECHNO-BASIS»*
Анатерм-501	*red*	*0,6 mm*	*-60…+150*	*Federal State Unitary Enterprise «Research Institute of Polymers»*
Anaerobic Flange Sealant	*red*	*0,38 mm*	*-54…+149*	*Permatex (USA)*
LOCTITE-577	*yellow*	*-*	*-55…+150*	*LOCTITE*

The carried out investigations display high efficiency of application of anaerobic adhesive polymers in their pure form and with application of different fillers allowing to obtain the required adhesive properties [6,7].

For hermetization of cracks in body parts, with wall thickness more than 3 mm (fig 1(a)) it is rational to use specially developed for these purposes anaerobic sealants of the Russian production. Anaerobic sealants are liquids of different viscosity and which are capable to remain in the initial state without changing properties for a long time and to harden quickly in narrow clearances at temperature 15-35 ^{0}C after terminating the contact with aerial oxygen, with firm polymer layer formation.

These sealants after hardening possess high thermal and chemical resistibility, providing the required operational capability of joints and parts even at their operation in contact with organic solvents, aggressive media at temperature from -50 to +150 ^{0}C.

Since crack, as a rule, has no constant clearance, repair kit has two adhesive compositions. Composition АН-1У has excessive penetrating capacity and hardens at clearance not less than 0,1 mm. Plymer Уг-7 has excessive viscosity and hardens at clearance up to 0,2 mm.

Microcrack hermetization technology is in the following. Crack is ungreased («transfused») with acetone or gazoline, blow off with compressed air and is dried. The item should be set in a way that crack is placed vertically. It is necessary to apply several times from flask sealer of trademark АН-1У (red) with less viscosity and having excessive penetrating capacity. After an hour exposition at room temperature, the crack is transfused with more viscous sealer Уг-7 (green). Duration of sealer setting at room temperature is about 6 hours. Temperature increase reduces the hardening time, and decrease increases alternatively.

If there is an access to a crack as it is presented in fig. 1 (b), then in this case the following hermetization technology can be used. To prevent further crack spreading it is necessary to drill out its ends for thread M6. Then a plug with high impact anaerobic sealer applied on the thread is screwed into the prepared hole. At hermetization of long cracks for better item rigidity and for illumination of displacements between crack fractures, it is possible additionally along the crack to drill some analogical holes for thread, with the following mounting of threaded plugs on high impact sealer. While using different appliances it is possible to fill in vertical and overhead cracks, it allows sealing the crack without car unlocking.

With the help of anaerobic adhesives, it is possible to restore operating capacity of loose rolling bearing fit (fig. 2), in the body as well as on the shaft. Compositions Анатерм-6к and Анатерм-111 (Russia) allow to restore clearances up to 0,27 mm. At this, time of composition setting at room temperature is about 25-30 min, hardening is 5-6 h.

Figure 2. Restoration of rolling bearing fit

Adhesive compositions of the USA production are of a special interest: *Permatex® Bearing Mount for Close Fits* and *Permatex® Bearing mount for Worn.*

Fast setting anaerobic adhesive *Permatex® Bearing Mount for Close Fits* has low viscosity, which increases fit density. Diametric clearance at the given composition should not exceed 0,13 mm. Cream composition *Permatex® Bearing mount for Worn Parts* can be used at clearances up to 0,5 mm per diameter.

While using adhesion compositions a special attention should be paid to the quality of the restorable surface preparation. Before polymer application, the surface is carefully cleaned. It is descaled and derusted mechanically. The surfaces are ungreased with brush or cotton swabs soaked with gasoline or acetone and dried.

Anaerobic composition is applied from flask dropper on the whole outside surface of one of the associable parts and assemble the unit. It is necessary to pay attention that sealer will not get on retainer or bearing tracks.

At great wears, it is necessary to carry out operation on part center adjustment. Herewith it is possible to use centering inserts made of soft sheet metal or soft wire.

At restoration of identical part set, it is advisable to use purpose-made mandrels (fig. 3). For example, to provide bearing adjustment about an axis of shaft rotation is necessary one of the unworn areas of shaft surface should support that mandrel. In this case, bearing that is located in mandrel will be adjusted about shaft rotation axis.

The carried out investigations, displayed that the life of the restored in this way seat for rolling bearing turns out to be higher in comparison with junction without polymer layer. This is explained by the fact that adhesive composition between bearing body and case (shaft) provides more even load distribution between rolling bodies (fig. 4). Herewith more even load distribution between rolling bodies of bearing takes place and contact pressure on the working surfaces of bearing parts decreases. If bearing is set without polymer the loading is concentrated on one rolling body (fig. 5), at that this concentration increases at joint clearance growing, this reduces dramatically bearing life. It should be pointed out that polymer layer protects surfaces from corrosion.

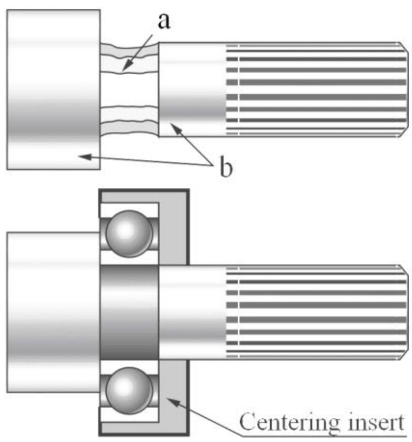


Figure 3. Bearing adjustment about shaft by mandrel:
a – irregularly worn seat for bearing; b – unworn shaft part

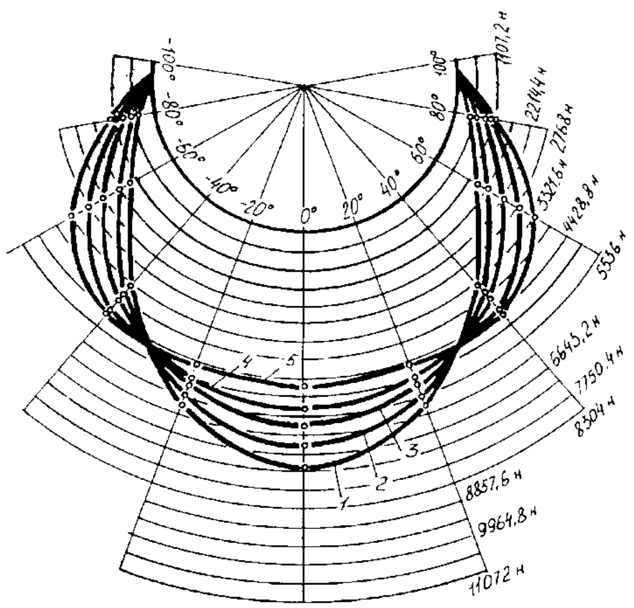


Figure 4. Loading distribution in rolling bearing at its installation on polymer of different thickness:1 – 0,008 mm; 2 – 0,053 mm; 3 – 0,098 mm; 4 – 0,139 mm; 5 – 0,182 mm.

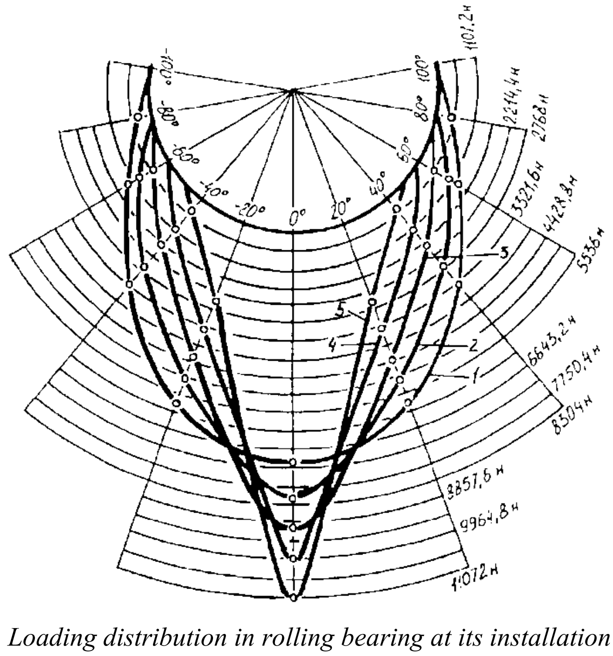


Figure 5. Loading distribution in rolling bearing at its installation without polymer: 1 – tension 0,005 mm; 2 – clearance 0,057 mm; 3 – clearance 0,123 mm; 4 – clearance 0,236 mm; 5 – clearance 0,336 mm.

CONCLUSIONS

The example cases of adhesive application are demonstration of only some the most frequent defects. In practice the sphere of their application can be considerably broaden. Anaerobic adhesive compositions can be successfully applied by repair and technical enterprises and in some cases, they not only allow substitution of welding, deposition, soldering but restore operating capacity of joints and assemblies, which repair by conventional methods is impossible or problematic. Knowledge of properties and characteristics of adhesive materials allows being aware easily in the sphere of different compositions commercially available, choosing the necessary and applying them in the right way.

REFERENCES

[1] Ašonja, N.A., Pastuhov, G.A. 2014. Uticaj dijagnostike stanja na pouzdanost dvostr poljoprivrednih kardanskih vratila. *Poljoprivredna tehnika*, vol. 39, No. 1, p.p. 21-30.

[2] Kravchenko, I., Kuznetsov, Y., Bobryashov, E., Kolomeichenko, A. 2014. Plasma restoration and hardening of elements of tillage tools**.** *Poljoprivredna tehnika,* vol. 39, No. 4, pp. 91-99.

[3] Mileusnić, I.Z., Petrović, V.D., Miodragović, M.R., Dimitrijević, Aleksandra. 2010. Uticaj uslova eksploatacije traktora na njegovu pouzdanost i radni vek. *Poljoprivredna tehnika*, vol. 34, No. 1, pp. 59-67.

[4] Aronovich, D.A., Murokh, A.F., Sineokov, A.P. 2006. Thermal resistant anaerobic sealants and glues. *Plastic masses,* No. 6, p.p. 37-41.

[5] Ivanov, V.A., Shagunov, D.V., Baikin, S.D. 2012. Modernization of service equipment as a method of enlargement its technological capabilities. Electrotechnical and information complexes and systems, vol. 8, No. 2, pp. 2-8.

[6] Bashkirtsev, Yu.V., Klubnichkin, E.E., Nikishina, O.S. 2011. Utilization of adhesive composition for restoration of transport and technological machine parts of wood enterprises. Bulletin of Moscow State University of Forest – *Forest Bulletin,* No. 5, pp. 56-62.

[7] Bashkirtsev, Yu.V., Klubnichkin, E.E., Nikishina, O.S. 2011. Utilization of adhesive composition at repair. *Agricultural machine operator*, No. 3, pp. 34-35.

PRIMENA ANAEROBNIH LEPKOVA KOD POPRAVKI MAŠINA

Vladimir Bashkirtsev[1] , Yury Kuznetsov[*2], Larisa Kalashnikova[3]

[1]Ruska inžinjerska akademija za upravljanje i agrobiznis, "Chelyuskinsky" , Moskovski region, Ruska fedreracija
[2]Orel državni poljoprivredni Univerzitet, Orel, Ruska federacija
[3]Orel državni poljoprivredni Univerzitet, Orel, Ruska federacija

[*] Corresponding author. E-mail: kentury@rambler.ru

Sažetak: Prikazan je značaj primene anaerobnih lepkova tokom održavanja i remonta mašina. Analizirane su komparativne karakteristike anaerobnih kompozita (lepkova) i preporuke o adekvatnom izboru zaštitnog znaka adhezivnog materijala.
Predlažemo konvencionalne tehnologije restauracije radnih kapaciteta spojeva i sklopova koji su izgubili performanse prilikom rada sa anaerobnim lepkom.

Ključne reči: lepak, anaerobni sastav, polimer, popravak, restauracija, hermetizacija, fiksacija, odstojanje.

Prijavljen: *Submitted*: 29. 01. 2018.
Ispravljen: *Revised*: 12.03.2018
Prihvaćen: *Accepted*: 18.03.2018

Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XLIII
Broj 1, 2018.
Strane: 12-21

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XLIII
No. 1, 2018.
pp: 12-21

UDK:631.558.1:631.561 *Pregledni rad*

HIDROSTATIČKI SISTEMI PRENOSA SNAGE POLJOPRIVREDNIH MAŠINA: ZAPREMINSKE PUMPE

Vera B. Cerović[1], Dragan V. Petrović[1*]

[1]*Univerzitet u Beogradu, Mašinski fakultet, Kraljice Marije 27, 11000 Beograd*
[2] *Univerzitet u Beogradu, Poljoprivrednii fakultet, nemanjina 6, 11081 Beograd-Zemun*

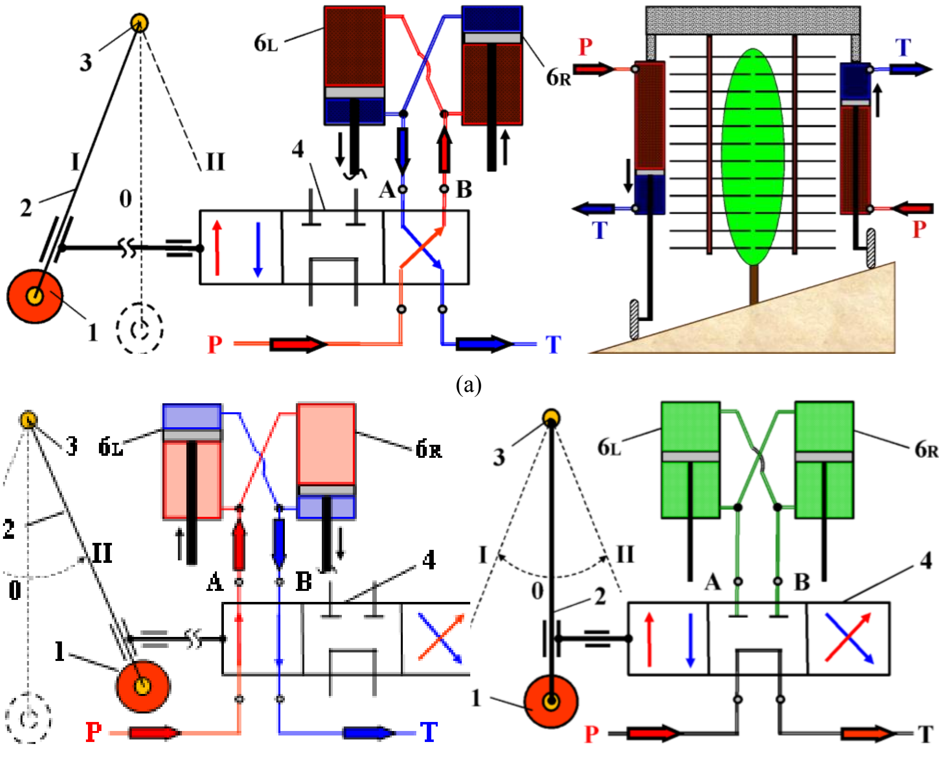
Sažetak: U radu je prikazan i analiziran hidrostatički prenos snage i upravljanja. Navedeni su najvažniji elementi ove grupe sistema i mogućnosti njihove primene u poljoprivrednoj tehnici. Posebno pažnja je posvećena zapreminskim pumpama koje nalaze najširu primenu u poljoprivrednoj mehanizaciji: zupčastim pumpama sa spoljašnjim i unutrašnjim ozubljenjem, krilnim pumpama, klipno-aksijalnim pumpama sa nagnutom kliznom pločom i klipno-aksijalnim pumpama sa nagnutim cilindarskim blokom. Prikazana su dva hidrostatička sistema prenosa snage i upravljanja.Prvi predstavlja veoma jednostavan mehaničko-hidraulički sistem automatske nivelacije samohodnog berača jagodastog voća.Drugi predstavljeni hidrostatički sistem spada u najsavremenije sisteme koji se koriste u poljoprivrednoj mehanizaciji. Izveden je kao veoma složena kombinacija hidrostatičkog i mehaničkog prenosnika snage sa pratećim upravljačkim digitalnim elektronskim sistemom, a namenjen je pogonu žitnog kombajna.

Ključne reči: *hidraulika, prenosnik, poljoprivreda, mehanizacija, pritisak, protok*

UVOD

[1*]Kontakt autor E-mail adresa: epetrodr@agrif.bg.ac.rs
Rad je nastao u okviru projekta: „*Unapređenje biotehnoloških postupaka u funkciji racional-nog korišćenja energije, povećanja produktivnosti i kvaliteta poljoprivrednih proizvoda*“, broj TR 31051, Ministarstva prosvete, nauke i tehnološkog razvoja R. Srbije.

Mehanički prenosnici često omogućavaju najednostavniji prenos energije između pogonskih i radnih mašina. Uporedo sa njima, sve složeniji zahtevi pri prenosu energije (promenljivost brzinekretanja, obrtnog momenta, učestanosti obrtanja, periodično prekidno kretanje itd. u širokom opsegu) inicirali su široku primenu hidrauličkih prenosnika snage i kretanja u svim oblastima tehnike, uključujući i poljoprivrednu. Hidraulički i mehanički sistemi su uglavnom spregnuti, uz podršku elektronskih sistema [5], [6].Tako je nastala nova naučna oblast – mehatronika [20]. Ipak, mehaničko upravljanje hidrauličkim sistemom i dalje je prisutno, kao npr. za automatsku nivelaciju samohodnog berača maline i kupine [21] prikazanog na slici 1. Klatno (1), povezano sa hidrauličkim razvodnikom sa mehaničkim upravljanjem (2) preko poluge, nastoji da zauzme vertikalan položaj. Time se hidraulički razvodnik (4) automatski postavlja u optimalni položaj i izravnava kombajn suprotnosmernimaktiviranjem cilindara (6L,R).



Slika 1. Sistem nivelacije: (a) podizanje desnog i spuštanje levog točka pri radu na nagibu (b) obrnut proces poravnavanja i (c) neutralno stanje na vodoravnom terenu, [21].

Figure 1. The leveling system: (a) right wheel liftingandleft wheel loweringat sloped terrain, (b) vice versa process and(c)neutral position at horizontal terrain, [21].

Pri formiranju hidrauličkog sistema za predviđene uslove rada i namene, potrebnoje izabrati pogodan radni fluid istandardne hidrauličke komponente, povezati ih i funkcionalno uskladiti.Stabilan rad sistema u dinamičkim uslovima nije zagarantovan i može zahtevati primenu matematičkog modeliranja ponašanja sistema [16].U poljoprivrednoj tehnici su ovi problemi retki, ali se matematičko modeliranje ipak koristi.

Ispravan rad hidrauličkog sistema zahteva obezbeđivanje potrebne količine prečišćene radne tečnosti, pumpe sa pokretačkim elementom (SUS ili elektromotor) i po potrebi mehaničkog prenosnika snage između njih, upravljačkihi sigurnosnihventila, izvršnih elemenata,rezervoara radne tečnosti,cevi koje ih povezuju itd. Ispravni, usklađeni, pravilno odabrani i povezani elementi moraju izvršavati svoj pojedinačni zadatak, ali i obezbediti ispravno funkcionisanje hidrauličkog sistema kao celine [8].

Vremenom, usled habanja i starenja,mogu nastupiti problemi počevši od curenja radne tečnosti pa do otkazivanja elemenata hidrauličkog sistema. Uspešna dijagnostika i otklanjanje kvarova, kao i redovno održavanje i opzimizacija hidrauličkog sistema, zahtevaju poznavanje funkcionalnih principa svih elemenata i celokupnog sistema.To je neophodan uslov za za postizanja visoke efikasnosti, pouzdanosti i dugotrajnosti [3], [15], [22].Posebna pažnja se u poslednje vreme posvećuje razvoju i primeni ekološki podobnih hidrauličnih radnih tečnosti [10], [13], [14], [23], kao i njihovoj reciklaži [25].

Prema načinu prenosa snage (energije), razlikuju se dva osnovna tipa hidrauličkih sisema.Hidrodinamički sistemi prenose energiju u najvećoj meri posredstvom kinetičke energije (brzine strujanja) radne tečnosti. Nasuprot njima, hidrostatički sistemi koriste pritisak (potencijalnu energiju) radne tečnosti, dok je učešće kinetičke energije vrlo malo (često ispod 1%)[4]. U fokusu rada su hidrostatički sistemi prenosa snageu poljoprivrednoj mehaniziciji: kod traktora [7], [13], [17], [20], kombajna [1], [2], [8], [19], [21], priključnih mašina u voćarskoj[16], [18], [29], [30], [31], ratarskoj [1], [10], [26], [27], [28], [32] i stočarskoj proizvodnji [24], kao i kod pomoćnih uređaja [12].

U radu su prikazani najvažniji tipovi zapreminskih pumpi i njihove osobine i namena.Dati su i neki ilustrativni primeri njihove primene u poljoprivrednim mašinama.

MATERIJAL I METODE RADA

Radni fluidi hidrauličkih sistema su hidraulička ulja, kao medijumi za prenos snage (energije) sa jednog mesta na drugo. U granicama stepena korisnosti dizel motora, energija goriva se pretvara u mehaničku i preko vratila predaje pumpi kao pogonskom elementu hidrauličkog sistema.

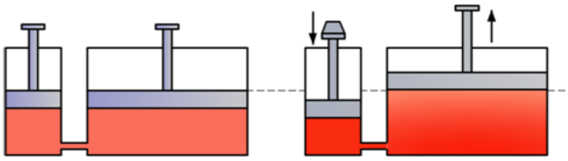
Dva su osnovna procesa u radu pumpe: usisavanje i potiskivanje tečnosti. U fazi usisavanja radni elementi pumpe stvaraju podpritisak u njenim komorama u odnosu na rezervoar ulja, pa ulje ulazi u te radne komore. U fazi potiskivanja radni elementi potiskuju tečnost ka izlazu saopštavajući pumpi potreban pritisak i brzinu (energiju). U zavisnosti od karakteristika kretanja radnih elemenata, zapreminske pumpe se dele u dve osnovne grupe: obrtne (zupčaste, krilne i zavojne) i translatorne (klipne i membranske).

Pumpa u svom radnom prostoru prenosi energiju na radni fluid. Kod hidrostatičkih sistema koriste se zapreminske pumpe, a energija jedinice mase radne tečnosti se povećava skoro isključivo povećanjem njenog statičkog pritiska. U odnosu na mehaničke prenosnike, hidrauličko ulje ima prednost pokretljivosti i prenošenja potencijalne (pritisne) energije ravnomerno kroz fluid u svim pravcima.

Prenos energije je nesavršen proces praćen gubicima energije.Deo energije se usled viskoznosti hidrauličkog ulja pri njegovom strujanja u random kolu i kućištu pumpe pretvara u toplotu.

Ovaj fenomen, označen kao disipacija, zajedno sa mehaničkim trenjem u ležajevima pumpe itd., prouzrokuje zagrevanje pumpe i radne tečnosti u toku rada pumpe, smanjujući energiju prenetu radnoj mašini za vršenje korisnog rada.

Efekti viskoznosti radne tečnosti se ispoljavaju i pri strujanju ulja kroz cevovode, crevovode, ventile, kolena, račve, difuzore, konfuzore i druge elemente hidrauličkih sistema.



Slika. 1.1. Osnovni princip rada hidrostatičkog prenosnika - pojačavanje radne sile

Figure 1.1.Basic operating principle of hydrostatic transmitter – force amplification.

Mada se često kombinuju sa elektronskim sistemima upravljanja, hidraulički sistemi imaju niz prednosti u poređenju sa mehaničkim i električnim prenosnicima snage:

- Fleksibilnost – zahvaljujući savitljivim elastičnim crevima, snaga se može prenositi skoro na svaku lokaciju, pa čak i menjati radnu lokaciju u toku rada.
- Kompaktnost i mala masa - prenose više snage od drugih sistema iste veličine.
- Jednostavnost i malo habanje - hidraulički sistemi poseduju manje pokretnih elemenata od ostalih sistema, manji broj nosivih tačaka i samopodmazivi su.
- Pouzdanost. Zasniva se na manjem broju pokretnih elemenata, električnih kontakatai lakšoj zaštiti od preopterećenja,u poređenju sa ostalim sistemima.
- Kontinualna i bezudarna promena brzine, broja obrtaja i radne sile ili obrtnog momenta u širokom opsegu.
- Jednostavna promena smera kretanja (ili obrtanja).
- Lako transformisanje obrtnog u translatorno kretanje i obrnuto.
- Pojačanje sile u širokom opsegu - dejstvom sile na manji klip može se dobiti veća sila na klipu većeg prečnika, srazmerno odnosu površina klipova (slika 1.1.).

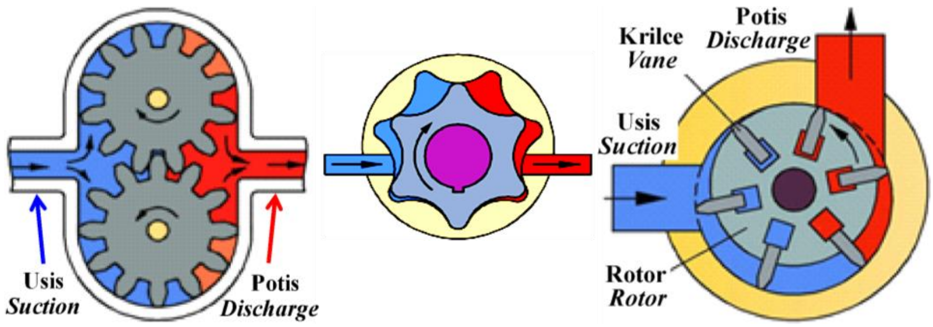
Ipak, nedostaci hidrauličkih sistema, mada retko, mogu ograničiti njihovu upotrebu:

- Efikasnost – je niža od mehaničkih sistema prenosa snage.
- Visoki zahtevi u pogledu čistoće i održavanja u poređenju sa drugim sistemima. Korozija, vlaga, nečistoće, toplota i starenje radne tečnosti mogu oštetiti hidraulički system, smanjiti ili potpuno sprečiti protok ulja u sistemu.
- Zavisnost sistema od spoljne temperature i temperature fluida.
- Opasnost od curenja radne tečnosti usled visokih radnih pritisaka.

OSNOVNI TIPOVI PUMPI

Određivanje mogućeg mesta ugradnje i izbor elemenata hidrostatičkog hidrauličkog sistema zahteva dobro poznavanje funkcionisanja odgovarajuće poljoprivredne mašine. Sistem se formira od raznih komercijalno raspoloživih elemenata. Glavni element svakog hidrostatičkog sistema je zapreminska pumpa.Danas postoji različite konstrukcije hidrauličkih pumpi. Ipak, u hidrostatičkim sistema prenosa snage kod kojih je samo minimalno curenje (povratno strujanje) radne tečnosti dopustivo, primenjuju se isključivo zapreminske pumpe (engl. *positive displacement pumps*).

Termin “zapreminska” označava svojstvo ovih pumpi da pri svakom punom obrtaju pogonskog vratila pumpa potisne istu zapreminu tečnosti (idealna zapremina) u hidraulički sistem. Treba napomenuti da stvarna zapremina potisnute tečnosti zavisi od zapreminske efikasnosti pumpe pri datom pritisku radne tečnosti. Zato protok tečnosti kod ovih pumpi zavisi od broja obrtaja u minuti pogonskog vratila.



(a) (b) (c)

Slika 2. Zapreminske pumpe: (a)-zupčasta pumpa sa spoljašnjim ozubljenjem (b)-zupčasta sa unutrašnjim ozubljenjem (rotor) pumpa; (c)-krilna pumpa.

Figure 2. The volumetric pumps: (a)-external gear pump; (b)-internal gear pump; (c)-vane pump.

Hidrostatički sistemi poljoprivrednih mašina uključuju jednu ili više pumpi. Primena jedne zupčaste pumpe sa spoljašnjim ozubljenjem za pogon svih uređaja je uobičajeni izbor (slika 2a), ali se koriste i drugi tipovi zapremniskih pumpi: zupčaste hidrauličke pumpe sa unutrašnjim ozubljenjem (slika 2b) i krilne pumpe (slika 2c).Konstrukcija rotacionih pumpi i motora je u osnovi jednaka, ili veoma slična, pa se često ista mašina može prema potrebi upotrebljavati kao hidraulička pumpa ili motor.

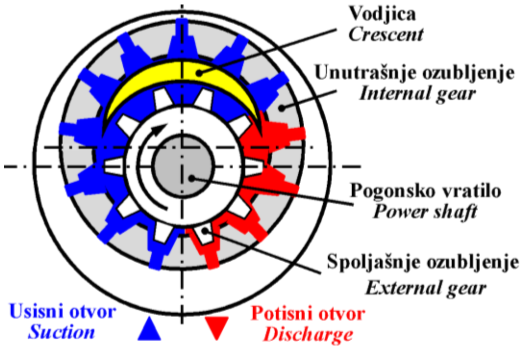
Zupčasta ili krilna pumpa se najčešće koriste zbog svoje jednostavnosti i cene. One zadovoljavaju tražene snage i protoke sa gledišta potreba poljoprivredne mehanizacije. Isporučuju stalnu zapreminu ulja po svakoj rotaciji vratila, tako da ukupni protok ulja zavisi isključivo od učestanosti obrtanja vratila pumpe. Izuzetak od ovog pravila je krilna pumpa čiji se rotor može zakretati.

Radni elementi zupčaste pumpe su zupci zupčanika, a njene radne komore su prostori međuzublja. Generalno, se razlikuju dve osnovne grupe ovih pumpi: sa spoljašnjim ozubljenjem (oba zupčanika) i unutrašnjim ozubljenjem (jedan zupčanik, a drugi i dalje ima spoljašnje ozubljenje). U okviru pumpi sa unutrašnjim ozubljenjem razlukuju se zupčaste pumpe sa srpom (slika 3) i rotor pumpe (slika 2b).

Zupčaste pumpe sa spoljašnjim ozubljenjem rade u opsegu temperature -20^{O}C do 80^{O}C. Male su zapremine i mase po jedinici predate snage, jeftine i jednostavne za održavanje i nisu osetljive na prisustvo sitnih nečistoća u ulju. Namenjene su ostvarivanju niskih i srednjih pritisaka (do 200/250 bar) i relativno velikih protoka (od 1 do 160 l/min), a rade pri učestanosti obrtanja od 1000 do 2000 min^{-1}. Ostvaruju zapreminski stepen korisnosti ukupni je $\eta_V = 0{,}9 - 0{,}95$, a ukupni je $\eta = 0{,}8 - 0{,}85$. Po pravilu su ireverzibilne, odnosno mogu da rade samo u predviđenom smeru obrtanja.Bučne su (nivo buke prelazi 70 dB) pri visokim pritiscima i učestanostima obrtanja.

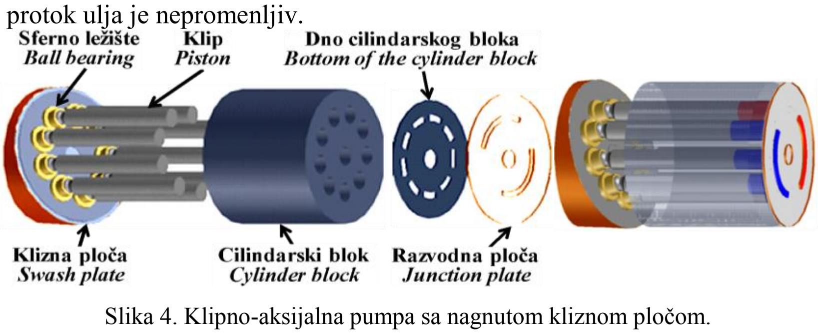
Pumpe sa unutrašnjim ozubljenjem (slika 2b i slika 3) rade na isti način kao i zupčaste pumpe sa spoljašnjim ozubljenjem (slika 2a). Njihov smer potiskivanja, protok i radni pritisak ne mogu se u toku rada podešavati (pumpe stalnog protoka).

Iz osnovne konstrukcije zupčaste pumpe sa unutrašnjim ozubljenjem i vodjicom, prikazane na slici 3, razvila se zupčasta "Gerotor"pumpa. Kinematika oba tipa pumpi sa unutrašnjim ozubljenjem je slična, ali kod "Gerotor" pumpe zupčanik sa spoljašnjim ozubljenjem ima jedan zub manje od zupčanika sa unutrašnjim ozubljenjem. Ova geometrija osigurava potpuno odvajanje usisne zone niskog pritiska od potisne zone visokog pritiska i otklanja potrebu za primenom vodjice. Kompaktne su konstrukcije, mirno i tiho rade, ali su nešto skuplje od zupčaste pumpe sa spoljašnjim ozubljenjem.

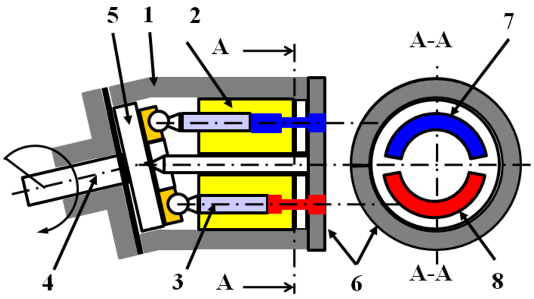


Slika 3. Zupčasta sa unutrašnjim ozubljenjem i vođicom (srpom).
Figure 3. Internal gear pump with crescent.

Krilne pumpe imaju najčešće 10 do 12 krilaca, a radna komora je prostor između njih i statora pumpe. Rotor je ekscentrično postavljen u statoru. Krilca se pod dejstvom opruge i/ili centrifugalne sile izvlače i uvlače, naležući na unutrašnju površ statora. Time se ostvaruje zaptivanje, promena zapremina komora, potiskivanje i povećanje pritiska ulja na potisu pumpe. Rade na niskim i srednjim pritiscima i omogućavaju veliki, ali stalni protok ulja. Male su mase i zapremine po jedinici snage.Mirno i tiho rade. Osetljive su na skokove pritiska, koji mogu polomiti krilca. Ostvaruju zapreminski stepen korisnosti $\eta_V = 0{,}9 - 0{,}95$, a ukupni je $\eta = 0{,}8 - 0{,}85$. Često se ugrađuju u motorna vozila. Postoje konstrukcije varijabilnog protoka ulja, sa zakretnim rotorom. Da bi se povećao protok, razvijene su krilne pumpe sa višekomornim kućištem - u svakoj komori se odvija po jedan proces usisavanja i potiskivanja radne tečnosti. Kod ovih pumpi protok ulja je nepromenljiv.



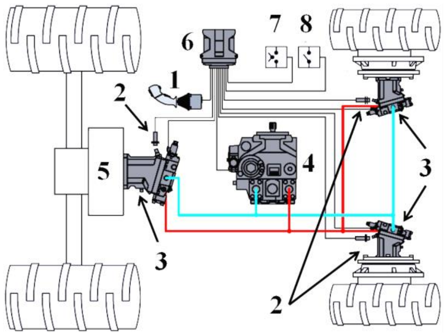
Slika 4. Klipno-aksijalna pumpa sa nagnutom kliznom pločom.
Figure 4.Axial piston pump, swash-plate principle.



Slika 5. Klipno-aksijalna pumpa sa nagnutim cilindarskim blokom: 1 - telo; 2 - cilindarski blok; 3 - klip; 4 - pogonsko vratilo; 5 – disk; razvodna ploča; 6 – usisni kanal; 7 – potisni kanal.
Figure 5. Axial piston pump with bent axis of the cylinders block: 1 - housing; 2 – cylinders block; 3 - piston; 4 – power shaft; 5 – disc; 6 – junction plate ploča; 6 – suction; 7 – discharge.

Postoje razni tipovi klipnih pumpi, u poljoprivrednoj mehanizaciji najviše se koriste dva tipa klipno-aksijalnih: sa pokretnom kosom kliznom pločom (slika 4) i nagnutim cilindarskim blokom (slika 5). Pumpe prve grupe su složenije konstrukcije i skuplje, ali omogućavaju kontinualnu promenu protoka radne tečnosti od nulte do maksimalne vrednosti, bez promene učestanosti obrtanja pogonskog vratila pumpe. Promena protoka se ostvaruje promenom nagiba klizne ploče prema osi vratila. Generalno, oba tipa klipno aksijalnih pumpi su složenije konstrukcije, većih gabarita i zahtevaju izuzetno preciznu izradu, te su i skuplje od zupčastih i krilnih pumpi, ali obezbeđuju veći protok i pritisak.

U poređenju sa pumpom za obezbeđenje cirkulacije rashladne tečnosti SUS motora, koja samo potiskuje rashladnu tečnost dozvoljavajući i povratno strujanje, klipno aksijalnepumpe usmeravaju tokhidrauličkog ulja u jednom smeru ali i sprečavaju povratno strujanje kada nisu u radu. Zato je rastojanje, između rotirajućih elemenata koji potiskuju ulje i kućišta pumpe, s namerom veoma malo (slike 4 i 5).



Slika 7.Hidrostatički pogon kombajna klipno-aksijalnim mašinama. [1].
Figure 7.Hydrostatic propuslion of harvester by piston-axial machines. [1].

Mobilne mašine često pokreće sprega klipno-aksijalnog motora i pumpe od kojih je jedan element varijabilnog, a drugi stalnog protoka. Šema ovakvog pogona kombajna data je na slici 7: 1 – džojstik; 2 – davač brzine; 3 –motori varijabilnog protoka; 4 –pumpa stalnog protoka; 5 – menjač; 6 –procesor; 7 – izbor hoda; 8 – izbor režima.

ZAKLJUČAK

U odsustvu prepreka strujanju radne tečnosti po izlasku iz pumpe, pad pritiska u hidrauličkom sistemu uslovljen je samo strujnim gubicima energije na savladavanje otpora pravolinijskih deonica cevovoda (linijski gubici) i lokalnim gubicima nastalim pri strujanju kroz svakiod ugrađenih elemenata: kolena, lukova, konfuzora, difuzora, račvi, filtera, ventila itd. Kod hidrostatičkih sistema, gubici energije radne tečnosti se u najvećoj meri svode na gubitak potencijalne energije - pad statičkog pritiska. Pumpa održava strujanje stalnom nadoknadom izgubljene energije po jedinici mase/zapremine tečnosti, odnosno pritiska.To rezultira odgovarajućim porastom pritiska radne tečnosti iza pumpe, u potisnoj strani visokog pritiska sistema. Strujni gubici hidrauličke energije u hidrostatičkom sistemu su po pravilu izuzetno mali, jer su brzine veoma male. Dodatnim prigušivanjem toka, npr. pritvaranjem ventila ili aktiviranjem hidrauličkog cilindra nastaje dalji porast pritiska ulja u delu sistema od pumpe do ventila ili cilindra.

Ispravno konstruisane i održavane pumpe imaju veoma male zazore (procepe) između svojih elemenata, te je mogućnost recirkulacije radne tečnosti unutar pumpe svedena na minimum. Stoga tečnost praktično nema drugu mogućnost struajnaja, osim kroz potisni deo cevovoda hidrostatičkog sistema ka potrošačima, što izaziva rast pritiska radne tečnosti koja izlazi iz pumpe. Ipak, nijedna pumpa nije idealno zaptivena i uvek postoji izvesno povratno strujanje (curenje) između pokretnih elemenata pumpe i njenog kućišta. Recirkulacija ima i dobru stranu, jer ovaj deo tečnosti podmazuje pokretne delove pumpe. Novije pumpe i pumpe sa većom otpornošću na trenje imaju veoma male zapreminske gubitke ulja usled povratnog strujanja fluida. Proces habanja elemenata hidrostatičke pumpe u toku radnog veka povećava zazore između njenih pokretnih i nepokretnih elemenata. Time se smanjuje njena mogućnost sprečavanja povratnog strujanja, kao i hidraulička energija i pritisak ulja na izlazu iz pumpe.

LITERATURA

[1] Anonimous 2017. *Mobile hydraulic solutions for Combine Harvester - Pumps and Motors, Orbital Motors and Valves for Propel and Work Function*. Broshure. Danfoss A/S ©.

[2] Chegini, R. G. 2013. Determine of Optimum Operating Conditions of Combine Harvester with Stripper-Header. *World Applied Sciences Journal*. 23(10): pp.1399-1407.

[3] Ebrahimi, E., Zarei, A., Astan N. 2015. Evaluation of an Intelligent System for Prediction of Hydraulic Pump Failure in Grain Combine Harvester. *Agricult. Communications*. 3(3): 26-32.

[4] Ercegović, Đ., Vukić, Đ., Raičević, D., Oljača M. 2006. Hidraulički sistemi prenosa snage u poljoprivrednoj tehnici. *Poljoprivredna tehnika*. 31(1): pp.101-112.

[5] Gligorević, K., Oljača, V. M., Ercegović, Đ., Pajić M., Zlatanović, I., Dražić, M., Dimitrovski, Z. 2010. Mogućnost primene laserskog sistema upravljanja radnim procesom univerzalnog skreperskog ravnjača. *Poljoprivredna tehnika*. 35(2): pp.11-18.

[6] Gligorević, K., Oljača, V. M., Ružičić, L., Radojević, R., Pajić, M. 2007. Uticaj elektronskih sistema na stabilnost vanputnih vozila. *Poljoprivredna tehnika*. 32(3): pp.11-18.

[7] Grozdanić, B., Borak, Đ., Petrović, V., Bracanović, Z. 2012. Optimizacija hidrauličnog podizača traktora IMR-a. *Poljoprivredna tehnika*. 36(4): pp. 89-94.

[8] Hassani, S. H., Jafari, A., Rafiee, S., Mohtasebi, S. S., Setayesh, M. A. 2011. Hydraulic System of JD 955 Combine Harvester as Well as Presented Services Based on Statistical Analysis. *Asian Journal of Agricultural Research*. 5(1): pp.67-75.

[9] Hunt, T. and Vaughan, N. 1996. *The Hydraulic Handbook*. Elsevier Science LTD., 9-thed.

[10] Isakov, S., Marinković, L., Mišković, Đ., Protulipac, T. 2009. Efekat prelaska sa konvencionalne na konzervacijsku obradu i setvu pšenice, soje, stočnog graška i pasulja. *Poljoprivredna tehnika*. 34(2): pp.115-124.

[11] Kladivar, Š. R., Svoljšak, M., Feldin, M., Vižintin, J. 2002. Rapidly Biodegradable Hydraulic Fluids on the Basis of Rapeseed Oil. *Goriva i Maziva*, 41(4): pp.199-225.

[12] Kodrič, M., Flašker, J., Pehan, S. 2017. Efficiency Improvement of Agricultural Winch Machines. Strojniški vestnik - Journal of Mechanical Engineering 63(3): pp.171-180.

[13] Kosiba, J., Zdenko Tkáč, Z., Hujo, Ľ., Tulik, J., Ševčík, P., Šinský, V., and Rašo, M. 2013. Effect of Ecological Energy Carriers on Flow Characteristics of Tractor Hydraulic Pump. *Journal of Central European Agriculture*, 14(4): pp.1415-1425.

[14] Kuĉera, M., Aleš, Z., Ivandić, Z., Ľ. Hujo Ľ. 2013. Possibility of hydraulic fluids with a low environmental impact application in agriculture and transport machinery. *Journal of Central European Agriculture*. 14(4): pp.1575-1584.

[15] Kuhar, E. J. 1992. *The fundamentals of service and theory of operation for hydraulic systems in off'road vechiles, trucks and automobiles*. John Deere Publishing, Illinois, USA.

[16] Marković, D., Veljić, M., Simonović, V., Marković, I. 2011. Matematička interpretacija parametara vibracionog dodavača voćapo modelu masa-opruga-prigušivač. *Poljoprivredna tehnika*. 36(3): pp. 93-98.

[17] Martinov, M., Đević, M., Novković, N., Savin, L., Ogrizović, B., Micković, G., Vidaković, V., Popović, M., Kekić, M. 2007. *Moj traktor*. Res Trade, Novi Sad, Republika Srbija.

[18] Mitrović, D., Manojlović, R. 2009. Tehnološki i eksploatacioni parametri mehanizovane sadnje loznih kalemova. *Poljoprivredna tehnika*. 34(3):71-75.

[19] Negrete, C. J. 2015. Informational and Conceptual Design of a Peanut Tractor Driven Harvester for Mexican Agriculture. *Poljoprivredna tehnika*. 40(4): pp. 9-18.

[20] Petrović, P., Obradović, D., Dumanović, Z., Micković, G., 2007. Informativni pregled primena mehatroničkih sistema kod savremenih poljoprivrednih traktora. *Poljoprivredna tehnika*. 32(3): pp.1-9.

[21] Petrović, V.D., Urošević, M., Radojević, L.R., Mileusnić, I.Z., Petrović, S., 2017. Razvoj hidrauličko-mehaničkog sistema automatske nivelacije berača maline i kupine. *Poljoprivredna tehnika*. 42(2): pp.1-10.

[22] Prasuhn, L. A. 1992. *Fundamentals of Hydraulic Engineering*. Oxford University Press Inc., New York, USA.

[23] Rusnák, J., Kadnár, M., Tóth, F. Kročko, M. 2013. Possibilities of using the ecological oil Arnica S 46 in agricultural engineering. *Journal of Central European Agriculture*, 14(4): pp.1444-1455.

[24] Radivojević, D., Topisirović, G., Ćirić, M. 2009. Ocena kvaliteta rada mikser distributer prikolice JF-STOLL u pripremi tmr obroka za muzne krave. *Poljoprivredna tehnika*. 34(4): pp.119-124.

[25] Ružić, D., Stojić, B. 2009. Ekološki pogodna manipulacija otpadnim materijama poljoprivredne mehanizacije.*Poljoprivredna tehnika*. 34(4): pp.37-44.

[26] Tekin B. A., Sındır, O. K. 2013. Variable Rate Control System Designed for Spinner Disc Fertilizer Spreader – "PreFer". *Poljoprivredna tehnika*. 38(2): pp.45-53.

[27] Veselinović, Š. Z. 2009. Priključna mašina za monofaznu kompleksnu agrotehniku. *Poljoprivredna tehnika*. 34(2): pp.1-8.

[28] Veljić, M., Živković, D., Marković, D. 2010. Operativna gotovost hidrauličnog podsistema agregata traktor-setvospremač. *Poljoprivredna tehnika*. 35(2): pp.27-36.

[29] Urošević, M., Živković, M., Komnenić, V. 2007. Eksploatacioni parametri tresača koštičavog voća domaće proizvodnje. *Poljoprivredna tehnika*. 32(3): pp.33-38.

[30] Živković, M., Urošević, M., Komenić, V., Dražić, D., Radivojević, D. 2009. Aspekti obrade zemljišta u višegodišnjim zasadima. *Poljoprivredna tehnika*. 34(3): pp.65-69.

[31] Živković, M., Urošević, M., Komnenić, V. 2008. Tehnološki i tehnički aspekti mehanizovane sadnje višegodišnjih zasada. *Poljoprivredna tehnika*. 33(3): pp.33-38.

[32] Živković, D., Veljić, M., Marković, D. 2009. Operativna gotovost setvospremača kao kriterijum uspešnosti održavanja. *Poljoprivredna tehnika*. 34(2): pp. 61-68.

HYDROSTATIC TRANSMISSION SYSTEMS OF POWER AND MOTION

Vera B. Cerović[1], Dragan V. Petrović[2*]

[1] *University of Belgrade, Faculty of Mechanical Engineering, Belgrade,*
[2*] *University of Belgrade, Faculty of Agriculture, Belgrade-Zemun*

Abstract: The paper presents and analyzes the hydrostatic transmission of power and motion. The most important elements of this group of systems and the possibilities of their application in agricultural technology are given. Particular attention is paid to the positive-displacement pumps that have the widest application in agricultural machinery: gear pumps with external and internal gears, vane pumps, piston-axial pumps with inclined swash plate and piston-axial pumps with inclined cylinder block. Two hydrostatic power transmission and control systems are also presented. The first is a very simple mechanical- hydraulic system of automatic leveling of self-propelled berry fruits harvester. In contrast, the other hydrostatic system is very sophisticated. It is implemented as a very complex combination of hydrostatic and mechanical power transmission subsystems, with the accompanying control digital electronic system, and is intended for the wheat harvester propulsion and steering.

Key words: *hydraulics, transmission, agriculture, machinery, pressure, flow*

Submitted: 15.02.2018
Revised: 21.02.2018
Accepted: 30.03.2018

[2*]Contact Author. E-mail adress: epetrodr@agrif.bg.ac.rs
This work is granted under project „*Improvement of biotechnological procedures as a function ofrational utilization of energy, agricultural products productivity and quality increase*“, No. TR 31051, founded by Ministry of education, science and technological development of Republic of Serbia.

Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XLIII
Broj 1, 2018.
Strane: 22 - 28

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XLIII
No.1, 2018.
pp: 22 - 28

UDK: 621.22 *Original research paper*

CFD SIMULATION OF THE FLOWING PROCESS THROUGH THE SHORT LENGTH SHARP EDGED ORIFICES

Sasko S. Dimitrov[1], Zoran M. Dimitrovski[1*]

Goce Delcev University, Faculty of Mechanical Engineering - Stip, Macedonia

Abstract: In this paper the static characteristics of the sharp edged orifices have been investigated. Mathematical relationship between pressure loss and flow through the orifice has been developed and solved for this type of orifices. A CFD simulation of the flowing process has been done. Full CAD model of the volume for orifices with different geometric parameters was created and meshed at finite number of elements. As a result of the CFD computations, few diagrams have been presented and compared to the theoretical ones. The discharge coefficient and the pressure loss coefficient have been obtained.

Key words: *orifice, pressure drop, flow, CFD, simulation, discharge coefficient.*

INTRODUCTION

The flowing and pressure drop through the sharp edged short orifices have been investigated long time ago. In [2] a model for discharge coefficient in the orifice is introduced as a function of the Reynolds number. According to this model, discharge coefficient calculation requires iterative procedure because Reynolds number also depends on the flow rate. To avoid this iterative procedure, in [3] an empirical discharge coefficient model for orifice flow is recommended. Another model for the discharge coefficient is described in [4] by Borutzky. Those models provide a linear relation through the orifice for small velocities while for turbulent flows, they match the conventional square root characteristics. Also, the transition from the laminar to the turbulent regime is smooth [5].

[1]* Corresponding author: Email: zoran.dimitrovski@ugd.edu.mk

In this paper a CFD method for simulation of the flowing process through the orifice is used, the pressure drop coefficient and the discharges coefficient have been determined and compared with numerical ones.

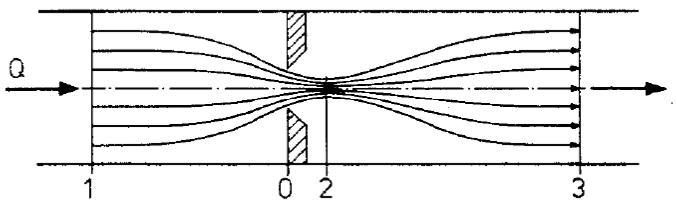


Figure 1. The short length sharp edged orifice

MATHEMATICAL MODELING

Steady state flowing process through an orifice is presented in figure 1. Well known dependence on flow of the pressure drop is [6]:

$$Q = \alpha_D \cdot A_0 \cdot \sqrt{\frac{2}{\rho} \cdot \Delta p} \tag{1}$$

where: Q −the flow through the orifice; α_D – the discharge coefficient; A_0 - the area of the orifice, $\Delta p = p_1 - p_3$- the pressure drop in the orifice.

Pressure drop in the sharp edged short orifice can be expressed by the equation:

$$\Delta p = \xi \cdot \frac{\rho}{2 \cdot A_0} \cdot Q^2 \tag{2}$$

Where: ξ - the local resistant coefficient.

Comparing the eq. (1) and (2), the dependence among the discharge coefficient and the pressure drop coefficient, is:

$$\alpha_D = \frac{1}{\sqrt{\xi}} \tag{3}$$

For $Re = 10 - 20000$ and $l/d = 1.5 - 10$, Lichtarowicz [7] has recommended an expression for discharge coefficient calculation:

$$\frac{1}{\alpha_D} = \frac{1}{\alpha_{Dmax}} + \frac{20}{Re} \cdot \left(1 + 2.25 \cdot \frac{l}{d}\right) \tag{4}$$

Where d - the orifice diameter; l - the orifice length.

Experimentally Wobben [8] has determined the maximal value of the discharges coefficient and it is $\alpha_{Dmax} = 0.83$.

Reynolds number for circle area is $= \frac{v \cdot d}{\nu} = \frac{4 \cdot Q}{d \cdot \pi \cdot \nu}$. Combining the last eq. for Re, into eq. (4) and introducing the correction factor $\left[\frac{20 \cdot \nu}{d} \cdot \left(1 + 2.25 \cdot (l/d)\right)\right]^2$, the final equation for flow calculation in a sharp edged orifice has been obtained:

$$Q = \alpha_{Dmax} \cdot \frac{\pi \cdot d^2}{4} \cdot \sqrt{\frac{2}{\rho} \cdot \Delta p + \left[\frac{20 \cdot \nu}{d} \cdot \left(1 + 2.25 \cdot (l/d)\right)\right]^2} -$$

$$-\alpha_{Dmax} \cdot 5 \cdot \pi \cdot d \cdot \nu \cdot \left(1 + 2.25 \cdot \frac{l}{d}\right) \qquad (5)$$

Knowing the geometric parameters of the orifice, applying eq. (5), it is possible to obtain the static characteristic of the orifice, i.e. the flow through the orifice depending on the pressure drop in the orifice.

CFD SIMULATION OF THE FLOWING PROCESS THROUGH THE ORIFICES

To identify the discharge coefficient and the pressure drop in the orifice, a series of steady-state CFD computations was performed with commercial CFD software package *FLUENT*. Three different sizes of orifices have been investigated*: 0.6 mm, 0.8 mm* and *1.0 mm*. *CAD* model of the fluid volume has been created and it has been divided into around 310000 elements, depending on the size of the orifice. The meshing model of the *0.8 mm* orifice is presented on figure 2.

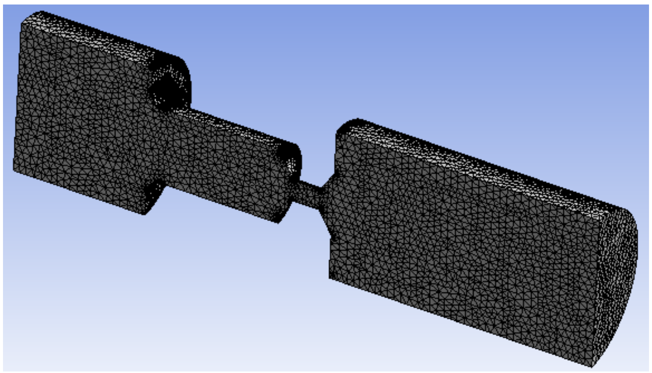


Figure 2. The CFD meshed geometry

As an input parameter was set the flow in the orifice. The output parameter, calculated by *FLUENT*, is the pressure drop through the orifice.

The results obtained by CFD simulation and the solution of the eq. (5) have been shown on fig.3. It is evident that there in very good match of the results between CFD simulation and the presented theory.

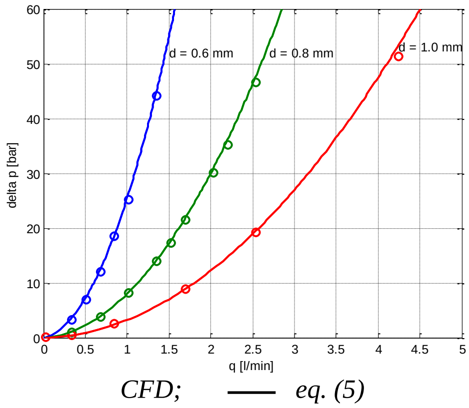


Figure 3. The static characteristics of the orifices

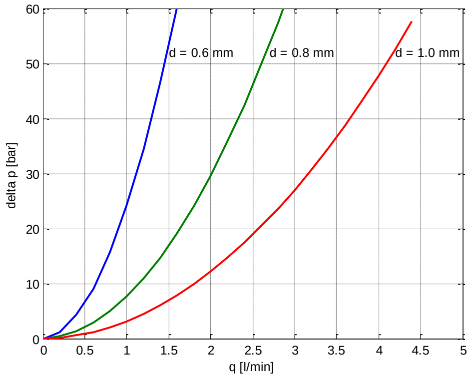
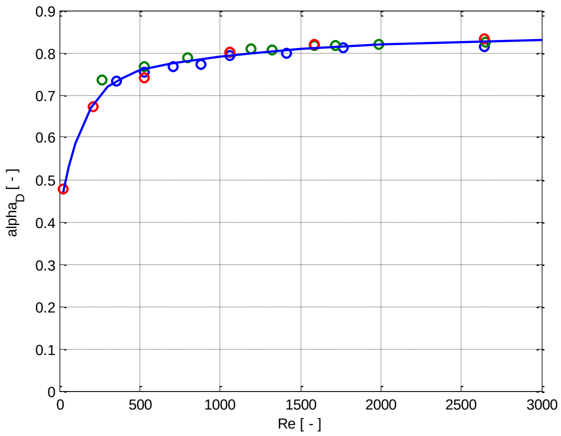


Figure 4. The theoretical static characteristics of the orifices

For simplicity of calculation, very often the pressure drop in the sharp edged orifice can be approximated by the eq. (2). According to this relation, for the local resistant coefficient $\xi = 1.48$, the curves on figure 5 have been obtained. It can be seen that there is good match between CFD simulation and relation (5) (figure 3) and the approximated eq. (2) figure 4. Applying the eq.(3), the flow coefficient is $\alpha_D = 0.822$, i.e. it tends to $\alpha_{Dmax} = 0.83$.

The values of the flow coefficient depending on the Reynolds number have been presented on figure 5. For turbulent regime of flowing the flow coefficient has constant value, but in the laminar regime of flowing, the flow coefficient is not constant, i.e. it varies depending on the average velocity of flowing in the orifice. If it is supposed using this sharp edged orifices in pilot pressure relief valves, usually the pilot flow in the pressure relief valves is around $1.0 - 1.5$ $[l/min]$. So the Re number does not exceed the value of 1500. For simplicity of calculation, in the dynamic model of the pilot operated pressure relief valve an average value of 0.8 for flow coefficient can be taken.



CFD; approximation
Figure 5. The discharge coefficient of the orifices

Figure 6 and figure 7 depict the pressure and velocity distribution for 0.8 mm sharp-edged orifice along the axis of the orifice. The pressure and velocity distribution do not differ qualitatively for different orifice diameters. The pressure drops quickly in the nozzle, then at the end of the nozzle the pressure little increase and then decrease and stay approximately constant. The velocity sharply rises in the nozzle and at the end of the nozzle begins to decrease.

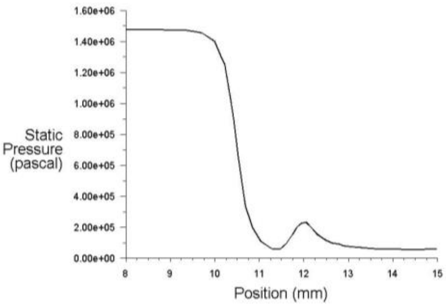


Figure 6. The pressure distribution along the orifice axis

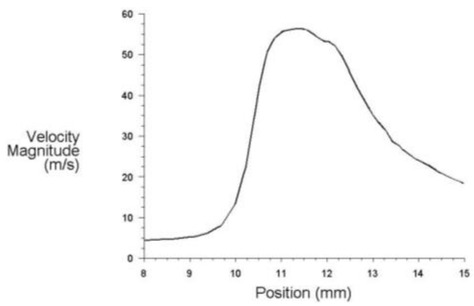


Figure 7. The velocity distribution along the orifice axis

Typical velocity contour and velocity vectors of $0.8\,mm$ orifice diameter, with $1.35\,\mathrm{l/min}$ and 14 bar pressure drop in the orifice is presented on figure 8 and figure 9. The velocity contours and velocity vectors do not differ qualitatively for different orifice diameters. As it is expected, the maximal velocity occurs at the nozzle where the diameter is the lowest.

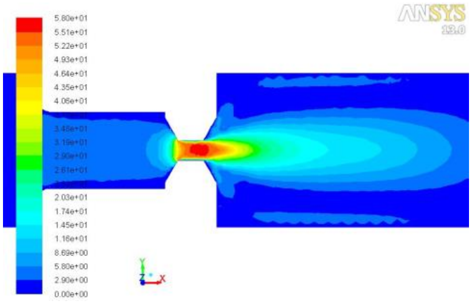


Figure 8. The velocity contour

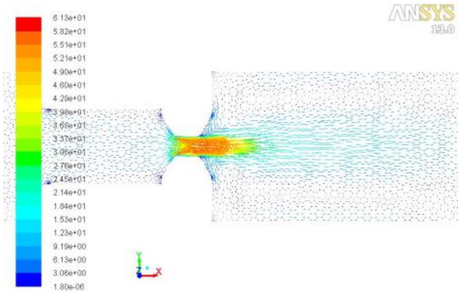


Figure 9. The velocity vectors

CONCLUSIONS

Mathematical relationship between flow and pressure loss in the sharp edged orifices has been developed in this paper. This mathematical model was confirmed with CFD simulation. CAD model of the flowing volume was created and simulation of the flowing process has been made. Graphically was compared the results of the CFD simulation and the solution of the eq. (5). The flow coefficient depending on the Reynolds number was obtained and presented graphically on fig.5. It can be seen that increasing the *Re* number the discharge coefficient tends to the value of *0.83* The pressure and velocity distribution along the orifice axis was depicted and the velocity contour and velocity vectors were shown (figure 8 and figure 9).

REFERENCES

[1] Komitovski, M., Dimitrov, S. 2013. “ Transient response process of a pilot operate pressure relief valve”, XVIII National Scientific with International Participation, FPEPM 2013, Sozopol, Bulgaria, pp. 139-145.

[2] Meritt, H.E., 1967. ”Hydraulic Control Systems”, John Wiley and Sons, 1967, 39-45.

[3] Wu, D., Burton, R., Schoenau, G. 2002. ”An Empirical Discharge Coefficient Model for Orifice Flow”, International Journal of Fluid Power – ISSN 1439-9776, Vol. 3, No. 3, 17-24.

[4] Borutzky, W., Barnard, B., Thoma, J. 2002. “An orifice flow model for laminar and turbulent conditions”, Simulation Modelling Practice and Theory, Elsevier Science B. V., Vol. 10, 2002. pp.141-152.

[5] Hos, C. 2005. “Dynamic Behavior of Hydraulic Drives”, Dissertation, Department for Hydrodynamic Systems, Budapest Univ. of Technology and Economics, Budapest, pp.16-23.

[6] Backé, W., Murrenhoff, H. 1994. “ Grundlagen der Ölhydraulik. Institut für fluidtechnische Antriebe und Steuerungen“, Technische Hochschule Aachen, pp. 26-28.

[7] Lichtarowicz, A., Duggins, R., Markland, E. 1965. “Discharge Coefficients for Incompressible NonCavitating Flow Through Long Orifices”, J. Mech. Eng. Sc. Nr. 2, pp. 210 – 219.

[8] Wobben, G.D. 1978. “Statisches und dynamisches Verhalten vorgesteuerter Druckbegrenzungsventile unter besonderer Berücksichtigung der Strömungskräfte“, Dissertation, RWTH Aachen, pp. 21-27.

CFD SIMULACIJA PROTOKA FLUIDA KROZ KRATKE PRIGUŠNICE SA OŠTRIM IVICAMA

Sasko S. Dimitrov, Zoran M. Dimitrovski

Universitet Goce Delcev, Mašinski fakultet - Štip, Republika Makedonija

Sažetak: U radu su istražene statičke karakteristike protoka fluida u prigušnicima oštrih ivica. Za ovaj tip otvora razvijen je i rešen matematički odnos gubitka pritiska i protoka kroz otvore. Prikazana i urađena je CFD simulacija protoka. Izrađen je CAD model zapremina protoka sa različitim geometrijskim parametrima podeljen konačnim brojem elemenata. Kao rezultat CFD proračuna, prikazani su dijagrami koji su upoređeni sa teoretskim dijagramom. U proračunu su dobijeni koeficijent protoka i koeficijent gubitka pritiska.

Key words: prigušnice, pad pritiska, protok, CFD simulacija, koeficijent protoka.

Prijavljen: 18.02.2018
Ispravljen: 18.03.2018
Prihvaćen: 23.03.2018

Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XLIII
Broj 1, 2018.
Strane: 29 – 38

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XLIII
No.1, 2018.
pp: 29 - 38

UDK: 631.3 *Pregledni rad*

PROBLEMATIKA UDESA SA POLJOPRIVREDNOM I ŠUMARSKOM TEHNIKOM U R. SLOVENIJI

Marjan Dolenšek[1], Robert Jerončic[2] , Kosta B. Gligorević[3], Mićo V. Oljača[3], Zoran Dimitrovski[4]

[1]Poljoprivredno šumarski zavod Ljubljana, Gospodinjska ulica 6, SI-1000 Ljubljana
Šumarski institut Slovenije, Večna pot 2., SI-1000 Ljubljana,
email: marjan.dolensek@gov.si
[2]Ministarstvo za infrastrukturu R. Slovenije, Langusova 4, SI 1535 Ljubljana,
email: Robert.Jeroncic@gov.si
[3]Univezitet u Beogradu, Poljoprivredni fakultet, Nemanjina 6. 11080 Zemun, R.Srbija,
email: koleg@agrif.bg.ac.rs, omico@agrif.bg.ac.rs
[4]Univezitet u Štipu, Mašinski fakultet, R.Makedonija,
email: zoran.dimitrovski@ugd.edu.mk

Sažetak: Poljoprivreda i šumarstvo su među radno intenzivnim sektorima gde poznavanje sigurnosti i zdravlja na radu nikada nije bilo dovoljno. Šumarstvo je poslednjih godina po opasnosti sa radnim udesima na samom vrhu a poljoprivreda je takođe vrlo visoko. Najviše udesa se događa šumarskom, a zatim sa poljoprivrednim tehnikom. U R.Sloveniji naročito je kritično stanje kod neprofesionalnih radnika, budući da radovi u šumarstvu i poljoprivredi nisu ograničeni samo na farmere, već se tom delatnošću bave svi koji imaju interes, vremena, zemljište ili šumu. Situacija nije problematična samo za pojedince koji rade u poljoprivredi i šumarstvu već i za društvo u celini. Budući da podaci o udesima neprofesionalnih radnika nisu precizno vođeni, detaljnija i precizna analiza uzroka udesa je otežana.

Ključne reči: *sigurnost i zdravlje na radu, poljoprivredna i šumarska tehnika, troškovi, propisi.*

[1] * Corresponding author: Email: marjan.dolensek@gov.si

UVOD

Poljoprivreda i šumarstvo su delatnosti u koje se još uvek polaže premalo pažnje i sigurnosti u toku rada. Šumarstvo je po rizicima na samom vrhu dogadjanja nesreća, a poljoprivreda je vrlo visoko rangirana. U R. Sloveniji, šume nisu samo veliko zeleno bogatstvo, već uzimaju i „najcrnji porez“ u ljudskim životima .

Posebno kritično stanje je u privatnom sektoru, budući da radovi u šumarstvu i poljoprivredi nisu ograničeni samo na profesionalce, već se tom delatnošću bave svi koji imaju interes, vreme i poljoprivredna imanja, zemlju ili šumu [1, 4, 5, 6, 7, 8]. Broj udesa u privatnom sektoru je zbog nepotpunih evidencija stvar više ili manje dobrih procena. Zato se analiza može osloniti na dosta potpune podatke o smrtno stradalima iz policijskih izveštaja [3, 10, 12, 13, 14, 15].

Međutim, u slučaju teških i lakih ozleda može se samo nagađati o njihovom broju i pomoći sa uporedbama iz inozemstva [9, 10, 12, 13, 20, 22, 23, 24, 25]. Zbog toga u analizi udesa u ovom radu postoje ograničenja na udese samo sa fatalnim ishodom.

Na području normativne regulacije sigurnosti i zdravlja na radu u poljoprivredi i šumarstvu u širem smislu, uključujući i sankcije za neprovođenje, primjenjuju se različiti propisi. Najvažnije su saobračajni propise i posebni propisi o sigurnosti i zdravlju na radu. Ali propisi su samo osnova, inače bi situacija u proteklim godinama bila bolja od postojeće [2, 3, 4, 5, 9]. približno 63% smrtnih slučajeva u poljoprivredi (R. Slovenija , R. Srbija) desi se u procesu korišćenja mašina [1, 2, 3, 4, 5, 7, 23, 25, 33]. Ovaj udeo je mnogo veći kod šumarstva u R. Sloveniji [5, 7, 8, 9, 10]. Na osnovu podataka sa prikazanom statistikom, Autori (R. Slovenija, R.Srbija) u istraživanjima navode [20, 22, 23, 24, 25, 26, 31, 32], da je u poljoprivredi (i šumarstvu) broj udesa najmanje 20% izazvano upotrebom mehanizacije i tehnike. Na istoj osnovi ti Autori (R. Slovenija, R. Srbija) procenjuju [1, 2, 6, 9, 20, 23, 24] da se kod 100 do 500 povreda skoro uvek najmanje dešava 1 (jedan) smrtni, tragičan slučaj .

Svaka pojedinačna smrt koja se dogodi zbog udesa ili drugog uzroka koji nije vezan za očekivani kraj ljudskog života, tragična je za pojedinca i njegovu neposrednu okolinu jer ljudski život nema cenu [4, 6, 9, 20, 23, 24]. Osim toga, svaka smrtnost također rezultira troškovima za uklanjanje posledica. Slično važi i za teške ozlede (invalidi), a u određenoj meri i za lakše ozlede i poremećaje funkcije normalnog zdravlja. Ove i slične troškove snosi rodbina pokojnika ili povređenih ljudi i na kraju uvek društvo u celini. Sa realnim poznavanjem uzroka udesa i troškova za rešavanje posledica moguće je planirati i organizovati delotvornije mere za sprečavanje udesa i druge preventivne metrode i mere [15, 16,17,18,19].

MATERIJAL I METODE RADA

Za analizu tragičnih desa sa poljoprivrednim i šumarskim mašinama (R. Slovenija) upotrebljeni su podaci Ministarstva unutrašnjih poslova od 1981. do 2017. godine [7,8,12], koji su o dostupni od kraja februara tekuće godine za prethodnu godinu. Takođe su upotrebljeni podatci iz analiza na temelju policijskih izveštaja o fatalnim udesima kod neprofesionalnih šumarskih radnika [5, 13, 9]. Do 2004 godine analizirani su podaci iz policijskih izveštaja za poljoprivredu na Savetu za sigurnost na cestama [3,18], i za šumarstvo [8].

Između 2005 i 2010. godine prekinuta je obrada podataka o nesrećama prema izveštajima MUP RS. Od 2013. godine Šumarski institut R.Slovenije nastavlja obradu podataka iz izveštaja MUP RS o nesrećama za poljoprivredu i šumarstvo, ali detaljni rezultati još nisu dostupni.

Podatke o udesima neprofesionalnih šumarskih radnika od 1998. godine prikuplja i Zavod za šumarstvo R.Slovenije i to na osnovu objava u medijima i obavijesti radnika zavoda [2, 9].

Podaci o novo registrovanim traktorima dobijeni su iz mesečnih izveštaja Ministarstva infrastrukture Republike Slovenije [14]. Prema podacima Ministarstva infrastrukture u R.Sloveniji je u februaru 2018 registrovano 110.043 dvoosovinskih traktora. Procena autora ovog rada je da u R.Sloveniji ima od 10.000 do 20.000 traktora koji nisu uključeni u statistiku jer oko 20% traktora nikada nije bilo registrovano [6]. Autori [6,7] sa velikom verovatnoćom zaključuju, da su svi kupljeni traktori, u poslednjih 15 godina bili registrovani .Podaci o svim smrtnim udesima na radnim mestima, dobijeni su iz godišnjih izveštaja Inspektorata rada Republike Slovenije [12,13]. Podaci o smrti u saobraćajnim udesima se nalaze na SI-STAT portalu [12].

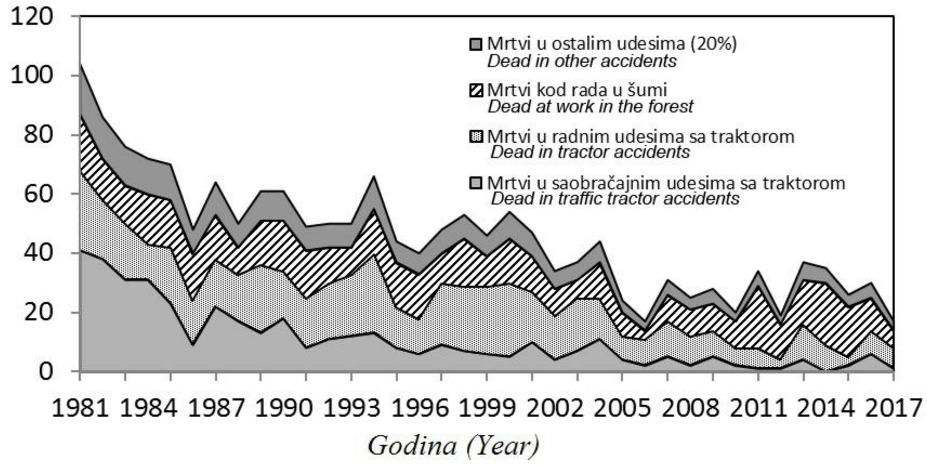
Procena društveno-ekonomskih troškova udesa sa poljoprivrednim i šumarskim mašinama procenjena je pomoću društveno-ekonomskih troškova saobraćajnih udesa [11, 15] Direkcije za ceste Republike Slovenije iz 2014 godine.

Podaci o subvencioniranju kupovine traktora u programskom razdoblju 2007 do 2013. godine Programa ruralnog razvoja, dobijeni su od Ministarstva poljoprivrede, šumarstva i prehrane [10].

REZULTATI ISTRAŽIVANJA I DISKUSIJA

Smrtno stradali u udesima u poljoprivredi i šumarstvu

Od 1981 do 2017. godine u rada sa poljoprivrednim i šumskim mašinama u R.Sloveniji smrtno je stradalo 1.419 osoba ili 38,4 godišnje. Po metodi Autora [9], dodaje se još 20% drugih tragičnih udesa (padovi u zgradama i poljoprivrednim objektima, povrede od životinja, trovanja hemikalijama itd.), u toku perioda 1981. do 2017. godina onda je u poljoprivredi i šumarstvu smrtno stradalo 1.687 osoba ili 45,6 osoba godišnje.



Grafik. 1. Smrtno stradali u poljoprivredi i šumarstvu R. Slovenije od 1981. do 2017. godine

Chart 1. Fatalities accident in agriculture and forestry R. Slovenia from 1981. to 2017.

Grafikon br.1. pokazuje da su na početku analiziranog vremenskog perioda prelomne (kritične) godine bile 1984., zbog ugradnje kabina za nove traktore i 1986. godina, sa obaveznim kabinama ali za sve traktore (i polovne) . Većina udesa dogodila sa traktorima koji nisu bili opremljeni kabinom ili sigurnosnim ramovima, kada je traktor usmrtio vozača. Opremanje traktora sa kabinama ili sigurnosnim ramovima u Republici Sloveniji, pokazuje takođe situaciju smanjenja smrtnih slučajeva [8], u poređenju sa Nemačkom i Austrijom, kada je u ovim državama propisana obaveza opremanja svih novih traktora (i polovni) sa kabinama ili sigurnosnim ramovima.

Na primer, u Nemačkoj je posle 10 godina nakon uvođenja obaveznog opremanja traktora na milion stanovnika smrtno stradalo 0,7 vozača traktora, u Austriji 4,8. Istovremeno je u Republici Sloveniji stradalo 16,8 vozača. Kako bi se poboljšala situacija Zakonom o motornih vozilima [16, 17] propisano je da traktori moraju imati kabinu ili sigurnosni ram. Odgovarajući Zakon u Republici Sloveniji omogućava i kontrolu i izricanje novčanih kazni od strane policije i inspekcijskih službi.

Tokom analiziranog perioda u Republici Sloveniji, do 2001. godine kod radova u šumarstvu u proseku smrtno je stradalo 18 ljudi godišnje. Manje od 10 nastradalih ljudi u šumarstvu bilo je 2004. do 2010. Ali u 2011. godini ponovo je registrovan je porast broja smrtnih slučajeva u šumarstvu od 14,7 ljudi godišnje.

Tabela 1: Smrtno (tragično) nastradali u poljoprivredi i šumarstvu Slovenije od 2008. do 2017.
Table 1. Fatalities accident in agriculture and forestry of Slovenia from 2008 to 2017

Godina *Year*	Mrtvi u saobraćajnim udesima sa traktorom *Dead person in traffic accident with tractor*	Mrtvi u radnim udesima sa traktorom *Dead person in agriculture with a tractor*	Mrtvi kod rada u šumi *Dead person in forestery with a tractor*	Mrtvi u ostalim udesima *Dead person in others accident with a tractor*	Ukupno *Total*
2008	2	10	9	4	25
2009	5	9	9	5	28
2010	2	6	9	3	20
2011	1	7	21	5	34
2012	1	3	12	3	19
2013	4	12	15	6	37
2014	0	9	21	5	35
2015	2	3	17	4	26
2016	6	8	11	5	30
2017	1	7	6	3	17
Ukupno/*Total*	24	74	130	43	271
Pros./*Average*	2,4	7,4	13,0	4,3	27,1

Tabela 1. prikazuje podatke za poslednjih 10 godina, gde je najproblematičniji rad mašina i ljudi u šumama. To se može pripisati osobito povećanom broju ljudi koji rade u manjim vlastitim šumama, koji nisu dovoljno tehnički obučeni, opremljeni i nedostaje takvim ljudima odgovarajuće iskustvo. Osim toga postoji rastući interes za proizvodnju drva za ogrev ili prodaje drva zbog lošije ekonomske situacije. Zbog navedenih glavnih razloga, povećan je obim i broj radova u šumama. Sa druge strane povećan obim radova u šumama se može javiti i kao uklanjanje posledica prirodnih nepogoda, naročito nevremena i velikih snežnih padavina kada se šume znatno oštete. Deo uzroka povećanih povreda ljudi u šumama takođe se može pripisati neadekvatnim propisima za rad u šumi, budući da za veliku većinu vlasnika šuma nije propisana stručna sprema ili oprema sa osobnom zaštitnom opremom i merama zaštite. Ova se obveza odnosi samo na 9.000 registrovanih izvođača radova u šumama i vlasnika šuma koji su osigurani kao poljoprivrednici. Autori na osnovu istraživanja [2,6,9] zaključuju da u šumama povremeno radi između 50.000 i 60.000 lica vlasnika šuma i članova njihovih porodica. Pošto velika većina ovih ljudi ne poznaje propise, Zakon, i pravila rada sa mašinama i traktorima u šumama, nesreće imaju veoma teške i ne predvidive posledice.

Upoređenje broja tragično stradalih u poljoprivredi i šumarstvu sa odabranim drugim oblastima

Aspekt upoređenja broja tragično nastradalih u poljoprivredi i šumarstvu u širem društvenom kontekstu, prikazan je upoređenjem broj tragično nastradalih u udesima svih zaposlenih, u saobraćajniim udesima i samoubistava u Republici Sloveniji. Za poređenje odabran je period od 2011. do 2012. (Tabela 2). Od odabranih područja za društvo u celini vidi se da su najproblematičniji samoubistva i saobraćaj, dok ima veliki broj smrtno stradalih u poljoprivredi i šumarstvu u proseku više nego kod udesa u ostalim radnim procesima (npr gradjevinarstvo, industrija) u Republici Sloveniji. Navedeno pokazuje veliku problematiku dogadjanja udesa u poljoprivredi i šumarstvu.

Tabela 2. Tragično (smrtno) nastradale osobe u odabranim oblastima nesreća
Table 2. Tragically (deadly) person killed in the selected areas of the accident

Godina *Year*	Udesi poljop./šume *Accident agric/forestery*	Svi radni udesi *All work accidents*	Udesi u saobraćaju Traffic accident	Samoubistva Suicides
2011	34	20	129	437
2012	19	21	122	443

Društveno ekonomski troškovi smrtnih udesa u poljoprivredi i šumarstvu

U slučaju nesreća na prvom su mestu posledice za pogođenog, rođake, prijatelje i praktički ne mogu biti vrednovani novcem. Međutim sa svakom takvom smrću dolazi do velikih društveno ekonomskih troškova.

Procena troškova najrazvijenija je za saobraćajne udese u R.Sloveniji. Prema studiji: -Procjena društveno ekonomskih troškova saobraćajnih udesa na cestama [3] u 2012. godini, troškovi za jednog smrtnog nastradalog u saobraćaju iznosili su 1,60 miliona eura.

Ako se jednako procene i posledice fatalnih udesa u poljoprivredi i šumarstvu one su u analiziranom 37 godišnjem periodu iznosili 2,70 milijardi eura, odnosno 2,3 milijarde eura u fatalnim udesima sa poljoprivrednim i šumarskim mašinama. To ukupno iznosi 1/4 godišnjeg bruto nacionalnog budžeta R. Slovenije za 2016. godinu. Ako se posmatra period 1981 do 2016., to prosečno iznosi 61,4 miliuna godišnje ili 0,71% bruto nacionalnog budžeta R. Slovenije za 2016. godinu.

Ako troškove za 37 godina analiziranih nesreća budu preračunati u mogući broj kupljenih novih traktora od 74 kW (100 KS) sa prosečnom cenom od 49,600 eura, to je ukupno 45.774 traktora ili 1.237 novih traktora svake godine.

Ipak je relevantnije ove troškove analizirati za poslednjih 10 godina. U ovom razdoblju u udesima povezanim sa poljoprivrednim i šumarskim mašinama smrtno je stradalo je 228 osoba. Prema predhodno opisanoj metodi [3] za poslednjih 10 godina predstavlja društveni trošak 365 miliona eura ili 7.354 novih traktora snage 74 kW. To relativno znači 48,6% svih prodanih traktora u istom razdoblju kada je bilo u R.Sloveniji prodano 15.122 novih traktora (različitih snaga).

Navedene konstatacije ilustruju na žalost istinsku veličinu društveno ekonomskih troškova posledica smrti vezanih za poljoprivredne i šumske radove i mašine .

Uticaj subvencioniranih ulaganja u poljoprivredne i šumarske mašine na poboljšanje stanja sigurnosti na radi

Svaki novi traktor ili mašina koji zamjenjuju staru znači veću i poboljšanu sigurnost i zdravlje na radu i tako utiču na smanjenje broja udesa i društveno ekonomskih troškova udesa. U R.Sloveniji prosečna starost traktora u 2010 godini iznosila je 20,6 godina. Preciznije to stanje je bilo prema [5, 6, 9]: 5% traktora mlađih od 5 godina, zatim 18% mlađe od 12 godina. Nažalost današnja situacija nije znatno bolja, pa je stoga potrošnja javnih sredstva koja se ulažu u subvencionisanje kupovine poljoprivredne i šumarske tehnike opravdana i značajna. U R.Sloveniji postoji široko prošireno mišljenje javnosti da poljoprivredna gazdinstva kupuju većinu mašina kroz subvencije, što nije tačno. U programu ruralnog razvoja za period od 2007. do 2013. godine samo je kupovina 13,8% novih traktora subvencionisana iz javnih sredstava R.Slovenije.

Naime, u zakonskim merama kojima je predviđeno sigurno povećanje ekonomske vrijednosti šuma i modernizacija poljoprivrednih gazdinstava [11a, 13, 15], subvencionisana je samo kupovina ukupno 1.536 traktora. Istovremeno je u istom razdoblju nabavljeno 11.500 novih traktora. Možemo zaključiti da postoji slična situacija u kod priključnih i samohodnih poljoprivrednih ili šumarskih mašina, ali to se ne može potvrditi brojevima, jer podaci o prodaji ovih mašina, za sada, nisu dostupni.

Nova i sigurnija tehnika pomaže u smanjenju broja udesa pa je stoga subvencionisanje kupovine iz javnih sredstava opravdano, ali je tih slučajeva daleko manje od prevladavajućeg mišljenja javnosti u R. Sloveniji.

ZAKLJUČAK

Poljoprivreda i šumarstvo su radno intenzivne delatnosti gde sigurnost i zdravlje na radu uviek nedostaje, odnosno ne posvećuje se dovoljna pažnja ovom faktoru rada ljudi. Naročito problematična je situacija sa neprofesionalnim radnicima jer se šumarstvom i poljoprivredom bave svi koji imaju nekakav interes, vremena i zemlju ili šumu.

Iako je u prošlosti uloženo mnogo energije, napora i mera za povećanje sigurnosti na radu u poljoprivredi i šumarstvu, svake godine smrtno strada ili se povredi veliki broj ljudi, naročito neprofesionalnih radnika na poljoprivrednim gazdinistvima, među kojima su i deca mlađa od 15 godina.

Uz nesreće pojedinaca i njihove probleme, nastali udesi uzrokuju velike društveno ekonomske finasijske troškove kod rešavanja problema posledica.

Glavni uzroci udesa i nesreća sa poljoprivrednim i šumarskim tehnikom su:

- podcenjivanje prisutne opasnosti i neodgovorno ponašanje (nepažnja, neodgovarajuće psihofizičko stanje radnika, umor, alkohol i drugi faktori),
- precenjivanje stvarnih sposobnosti učesnika,
- stara tehnika (stari traktori i druge mašine) i slaba tehnička oprema (smrtni udesi sa traktorima – prevrtanje traktora: oko 75% slučajeva bez sigurnosnih ramova ili kabine – kotrljanje niz nagib i poklapnje vozača),

- loša ili nedovoljna obučenost za rad, jer nove tehnologije u radnim procesima donose nove opasnostri (primer: 2 tragična udesa sa presama za okrugle bale i jedan sa mašinom u šumarstvu za sečenje drva),
- zanemarivanje obavezne upotrebe lične zaštitne opreme,
- prirodne nepogode i drugi neuobičajeni uslovi rada za koje radnici nisu obučeni ,
- nedovoljno normativno regulisani uslovi za rad neprofesionalnih radnika u šumama

LITERATURA

[1] Bernik, R., Dolenšek, M. *Analiza vpliva tehnične zakonodaje in trga na nesreče s traktorji v zadnjih 15 letih.* Acta agriculturae Slovenica 87, 2: pp. 365-380

[2] Beguš,J. *Analiza nezgod pri delu v gozdu med neprofesionalnimi delavci s poudarkom na analizi nezgod pri sanaciji žledoloma*. Ujma 29: pp.165-205

[3] Direkcija RS za ceste. 2014. *Vrednotenje družbeno ekonomskih stroškov saobraćajnih nesreč na cestah (posodobitev)*: pp.28.

[4] Dolenšek, M. *Številnih kmetov prerani grob : varnost in zdravje pri delu - stanje, predpisi*. Kmečki glas, 70, pp. 7-12.

[5] Dolenšek, M. *Varnost in zdravje pri delu v kmetijstvu in gozdarstvu*. Kmečki glas, 70, 27: 7

[6] Dolenšek, M. *Črna statistika: varnost in zdravje pri delu*. Kmetovalec, 81, 3: 32

[7] Dolenšek, M., Jerončič, R., Bernik, R., Oljača, M. V. *Udesi sa traktorima u Slovenije u periodu od poslednje tri decenije*. Poljoprivredna tehnika 35, 1-4: pp.83-88.

[8] Klun, J., Medved, M. *Fatal accidents in forestry in some European countries*. Croatian journal of forest engineering, 28, 1: pp. 55-62

[9] Medved, M., Dolenšek, M. 2000. *Nezgode v kmetijstvu in gozdarstvu - problem evidenc*. Zbornik referatov IV. mednarodna konferenca Globalna varnost: pp. 81-90.

[10] Ministrstvo za kmetijstvo gozdarstvo in prehrano. 2015. *Podatki o sofinanciranih investicijah v traktorje v Programu razvoja podeželja v obdobju 2007 – 2013.*

[11] Podatkovna zbirka poročil Inšpektorata RS za delo. http://www.id.gov.si/si/o_inspektoratu/javne_objave/letna_porocila/ (okt 2016)

[11a] Program razvoja podeželja R.Slovenije za razdoblje 2007-2013 (Uradni list RS, št. 73/08, 17/09 i 38/14), Službeni list RS, broj 73/08, 17/09 i 38/14.

[12] Podatkovni portal SI-STAT http://pxweb.stat.si/pxweb/Dialog/statfile2.asp (okt 2016)

[13] Podatkovni portal Nac. inštituta za javno zdravje http://www.nijz.si/sl/podatki (okt 2016)

[14] Podatkovni portal Ministrstva za infrastrukturo s področja prometa http://www.mzi.gov.si /si/delovna _podrocja/kopenski_promet/evidence_ motornih_vozil_in_ vozniskih_dovoljenj/statisticni_ podatki_s_podrocja_prometa/leto_2016/ (okt 2016)

[15] Portal nacionalnega interoperabilnostnega okvira http://nio.gov.si/nio/vstopna.nio (okt 2016)

[16] *Zakon o motornih vozilih* (Uradni list RS, št. 106/10, 23/15 in 68/16)

[17] *Zakon o varnosti in zdravju pri delu* (Uradni list RS, št. 43/11)

[18] Žlender, B. 2015. *Nesreče s traktorji.* Svet RS za preventivo in vzgojo v cestnem prometu (interno gradivo)

[19] Gligorević, B.K., Oljača, V.M., Ružičić, L., Radojević, R., Pajić, M. 2007. Uticaj elektronskih sistema na stabilnost vanputnih vozila. Poljoprivredna tehnika, Vol. 32, No. 3, pp. 11-19.

[20] Oljača, V.M., Kovačević, D., Radojević, R., Gligorević, B.K., Pajić, M., Dimitrovski, Z. 2010. Nesreće sa vozačima traktora u javnom saobraćaju Republike Srbije. *Poljoprivredna tehnika,* Vol. 35, No. 1, pp.75-82.

[21] Oljača, V.M., Vukić, Đ., Ercegović, Đ., Gligorević, B.K., Pajić, M., Božić, S., Radojević, R., Dimitrovski, Z. 2008b. Tehnička rešenja uređaja i opreme za povećanje sigurnosti rada mobilnih mašina i traktora u poljoprivredi. *Poljoprivredna tehnika,* Vol.33, No.1, pp.89-100.

[22] Dimitrovski, Z. 2006. Uzroci i posledice nesreća pri eksploataciji traktora u poljoprivredi. Doktorska disertacija. Univerzitet u Beogradu, Poljoprivredni fakultet, Zemun. pp.1-189.

[23] Dimitrovski, Z., Oljača, V.M., Gligorević, B.K., Ružičić, L. 2010. Nesreće sa traktorima na javnim putevima u Republici Makedoniji. *Poljoprivredna tehnika,* Vol. 35, No. 1, pp. 89-97.

[24] Dimitrovski, Z., Oljača, V.M., Gligorević, B.K., Ružičić, L., Jerončič, R. 2011b. Posledice učešća mladih osoba u nesrećama sa traktorima u republici Makedoniji. *Poljoprivredna tehnika,* Vol. 36, No.1, pp.63-69.

[25] Gligorević, B.K., Oljača, V.M., Pajić, M., Dimitrovski, Z., Dražić, M., Radojičić, D. 2012a. Nesreće sa vozačima traktora u javnom saobraćaju na teritoriji Beograda. *Poljoprivredna tehnika,* Vol. 37, No. 2, pp.71-79.

[26] Gligorević, B.K., Oljača, V.M., Pajić, M., Dražić, M., Topisirović, G. 2013. Impact of alcohol consumption on the number of accidents with tractors and agricultural machinery in the public transport of Republic of Serbia. Fifth Conference „Energy Efficiency and Agr.Engineering", Proceed., pp.247-255, Ruse, Bulgaria, 17-18 May. ISSN 1311-9974.

[27] Gligorević, B.K., Oljača, V.M., Ružičić, L., Radojević, R., Pajić, M. 2007. Uticaj elektronskih sistema na stabilnost vanputnih vozila. *Poljoprivredna tehnika,*, Vol. 32, No. 3, pp.11-19.

[28] Gligorević, B.K., Zlatanović, J.I., Oljača, V.M. 2008. Tehnički sistemi za klimatizaciju kabina poljoprivrednih i meliorativnih mašina. Poljop.tehnika, Vol. 33, No. 2, pp. 1-12.

[29] Gligorić, R., Nikolić, R., Furman, T., Savin, L., Hristov, S. 1998. Kriterijumi stabilnosti standardnih traktora na nagnutom terenu. Traktori i pogonske mašine, v. 3 (4) pp. 60-66.

[30] Oljača, V.M., Gligorević, B.K., Branković, M., Dimitrovski, Z., Tanevski, D. 2005. Primena elektronskih komponenata na traktorima i radnim mašinama u funkciji povećanja kontrole sigurnosti i eksploatacije. Poljoprivredna tehnika, Vol. 30, No. 1, pp. 107-118.

[31] Oljača, V.M., Gligorević, B.K., et al. 2007a. Opasnosti i nesreće u eksploataciji mobilne poljoprivredne mehanizacije u Republici Srbiji. Poljoprivredni fakultet, Univerzitet u Beogradu, Monografija, ISBN: 978-86-7834-023-1, COBISS.SR-ID 137747212.

[32] Oljača, V.M., Kovačević, D., Radojević, R., Gligorević, B.K., Pajić, M., Dimitrovski, Z. 2010. Nesreće sa vozačima traktora u javnom saobraćaju Republike Srbije. *Poljoprivredna tehnika,* Vol. 35, No. 1, pp.75-82.

[33] Oljača, V.M., Vukić, Đ., Ercegović, Đ., Gligorević, B.K., Pajić, M., Božić, S., Radojević, R., Dimitrovski, Z. 2008b. Tehnička rešenja uređaja i opreme za povećanje sigurnosti rada mobilnih mašina i traktora u poljoprivredi. *Poljoprivredna tehnika*, Vol.33, No.1, pp.89-100.

PROBLEMS OF ACCIDENTS WITH AGRICULTURAL AND FORESTRY MACHINERY IN R. SLOVENIA

Marjan Dolenšek[1], Robert Jerončic[2] , Kosta B. Gligorević[3], Mićo V. Oljača[3], Zoran Dimitrovski[4]

[1]Agricultural Forestry Institute Ljubljana, Gospodinjska ulica 6, SI-1000 Ljubljana
Slovenian Forestery Institute, Večna pot 2, SI-1000 Ljubljana,
email: marjan.dolensek@gov.si
[2]Ministry of Infrastructure of the Republic of Slovenia, Langusova 4, SI 1535 Ljubljana,
email: Robert.Jeroncic@gov.si
[3]University of Belgrade, Faculty of Agriculture, Nemanjina 6. 11080 Zemun, R.Serbia,
email: koleg@agrif.bg.ac.rs; omico@agrif.bg.ac.rs
[4]University of Stip, Faculty of mechanical engineering, R.Macedonia,
email: zoran.dimitrovski@ugd.edu.mk

Abstract: Agriculture and forestry are among the labor-intensive industries where knowledge about health and safety at work is never enough. In recent years, the risk of accidents in the workplace is in forestry at the top, as well as farming is very high. Most accidents happen with agricultural forestry and techniques. In R.Slovenia, circumstances in non-professional workers sector are especially very critical, because working in agriculture and forestry are not only involved farmers, but also everyone who has an interest, time and agricultural land or forest. However, the situation is not problematic only for individual forest and agricultural workers, but on the national level. The fact that the exact data of accidents in the non-professional workers sector are not exactly known demands detailed analyses about the causes of accidents.

Key words: *safety and health, agricultural and forest machinery, costs, legalization.*

Prijavljen: 15.02.2018
Ispravljen: 29.03.2018
Prihvaćen: 01.04.2018

Univerzitet u Beogradu Poljoprivredni fakultet Institut za poljoprivrednu tehniku Naučni časopis ***POLJOPRIVREDNA TEHNIKA*** Godina XLIII Broj 1, 2018. Strane: 39 – 51	University of Belgrade Faculty of Agriculture Institute of Agricultural Engineering Scientific Journal ***AGRICULTURAL ENGINEERING*** Year XLIII No.1, 2018. pp: 39 - 51

UDK:635.4;62-4 *Original research paper*

THIN LAYER MODELING AND DETERMINATION OF THERMODYNAMIC PROPERTIES OF TOMATO SLICES DURING HOT AIR DRYING

Nnaemeka Nwakuba[1]*, Osita Chukwuezie[2], Sabbas Asoegwu[3], Godfrey Nwandikom[3], Ngozi Okereke[3]

[1]Agricultural and Bioresources Engineering Department, Michael Okpara University of Agriculture, Umudike, P.M.B. 7267 Umuahia, Abia State, Nigeria.
[2]Agricultural and Bio-Environmental Engineering Department, Imo State Polytechnic, Umuagwo, P.M.B. 1472, Imo State, Nigeria.
[3]Agricultural and Bioresources Engineering Department, Federal University of Technology, P.M.B. 1526 Owerri, Imo State, Nigeria.

Abstract: The drying kinetics and determination of thermodynamic properties of sliced tomato samples during hot air drying in a hybrid solar-electric crop dryer were presented. One kilogram batch of freshly harvested tomato samples were sliced to 10 mm thickness and dried at varying air velocities (1.0, 1.5 and 2.0 ms^{-1}) and temperatures (50, 55, 60, 65, and 70°C) using the hybrid mode. In order to choose the best drying model, eight thin-layer mathematical models were fitted to the experimental data. The high values of coefficient of determination, R^2 and the low values of reduced sum of squares error (SSE) and root mean square error (RMSE) indicated that the Midilli *et al.* model adequately described the drying process of tomato slices, with its highest R^2 (0.9999), lowest SSE (0.1136) and lowest value of RMSE (0.0212) at 70°C temperature and 2.0 ms^{-1} air velocity. Arrhenius model was used to represent the drying constant as a function of temperature. The effective moisture diffusivity increased with increase in temperature and air velocity; with the highest value obtained at air velocity of 2.0 ms^{-1} and temperature of 70°C, whereas it was lowest at air velocity of 1.0 ms^{-1} and temperature of 50°C. The mean activation energy required to dry 1kg batch of 10 mm sliced tomato samples was 39.34 $kJmol^{-1}$. Enthalpy and Gibbs free energy values were found to decrease with increasing drying temperature as well as the entropy which also exothermically decreased with temperature. Recommendations for further studies were stated.

Keywords: Thermodynamic properties, drying kinetics, tomato slices, water desorption, activation energy.

INTRODUCTION

Tomato (*Lycopersicon esculentum L.*) is a perishable and seasonal crop generally grown and widely eaten in most countries including Nigeria. It is one of the valuable fruit vegetables which is economically rated to be the second most important vegetable crop after potato [1, 2]. In developing countries such as Nigeria, tomato is a seasonal product, characterized by being in good quality, rich in vitamins and minerals, high moisture (usually above 90% wet basis),

[1*] Corresponding author: Email : ***E-mail:** nrnwakuba@gmail.com

low fats contents especially at harvest, excessive and cheap in their seasons and scarce, costly and in bad quality during out of seasons [3, 4]. In order to make it available on the market as long as possible after harvest, the products are most often subjected to the drying process.

Its drying is a highly energy intensive operation as a result of the relatively high moisture content at harvest; and for this reason, considerable amounts of energy is required to heat the drying air so as to bring down the high moisture content to a safe storage level (usually 5 – 15% w.b.) at a temperature range of 35 – 65°C [3, 4].

In order to analyze the drying behaviour of an agricultural product during drying process, the study of its kinetics in thin layers is essential [5, 6, 7, 8]. Mathematical modeling involves predicting and simulating drying behaviour of certain parameters and processes in a unified manner regardless of the control mechanism, through empirical and phenomenological models [9, 10]. Several mathematical models such as the Midilli *et al.* model, Page model, Newton model, Fick's-diffusion model, Logarithmic model, Henderson and Pabis model *etc*. have been used to describe the thin layer drying process of agricultural products. These models which describe the characteristics of a particular product being dried are used to estimate the drying time of several products and also to generalize drying curves needed for dryer design and process optimization. The study of thermodynamic properties in the drying process of agricultural products aims to proffer solutions to problems related to stability and optimization of process conditions [10, 11]. It is necessary for optimal designing and dimensioning of crop dryers and other devices in various processes of preservation of product quality as well as in the proper understanding and provision of information on energy exchanges between one state of equilibrium to the other [10, 12]. Given the above, this study is circumscribed to model the drying kinetics and determine the thermodynamic properties of tomato slices at varying drying temperatures.

MATERIAL AND METHODS

Theoretical principles

The plot of moisture ratio with drying time obtained from the experimental data was used to represent the drying kinetics of tomato slices; since the initial value for moisture ratio is unity for each of the experiments, the moisture ratio curve will explain the drying behaviour better than that of moisture content curve [13]. Therefore, the moisture ratio, MR was calculated from Equation (1a) as [14]:

$$MR = \frac{M_t - M_e}{M_o - M_e} = e^{-kt} \tag{1a}$$

Where: M_t =Moisture content at any time, t (% db.); M_e = equilibrium moisture content (% db.); and M_o = initial moisture content (% db.), t = drying time (mins.), k = drying constant (min^{-1}).

The values of M_e are relatively small when compared to M_t and M_o, and thus had negligible error [15, 16, 17], therefore the moisture ratio was calculated as Equation (1b):

$$MR = \frac{M_t}{M_o} \tag{1b}$$

The drying rate, DR was obtained as expressed in Equation (2) [1]:

$$DR = \frac{M_{t+dt} - M_t}{M_O - M_e} \tag{2}$$

Where: M_{t+dt} = moisture content (%wet basis, wb) at time t+dt; M_t = Moisture content at time, t (% wb); t = drying time (mins.).

The drying curves were fitted to eight commonly known thin-layer drying models as shown in Table 1. The best of fit was obtained by using three statistical parameters: coefficient of determination (R^2), reduced sum of squares errors (χ^2), and root mean square error (RMSE) expressed as Equations (3) – (5) [5-10, 13, 15]:

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N}(MR_{pre} - MR_{exp.i})^2}{\sum_{i=1}^{N}(MR_{pre} - MR_{expi})^2}\right] \quad (3)$$

$$\chi^2 = \sum_{i=1}^{n} \frac{(MR_{exp.i} - MR_{pre,i})^2}{N - m} \quad (4)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(MR_{pre.} - MR_{exp,i})^2}{N}} \quad (5)$$

Where: $MR_{exp.\,i}$ = the ith experimental moisture ratio; $MR_{pred.i}$ = the ith predicted moisture ratio; N = number of observation; m = number of constants in the drying model; MR_{pre} = mean of predicted moisture ratio.

Table 1. Thin-layer drying models.

Model No.	*Model name*	*Model equation*	*References*
1	*Lewis*	$MR = e^{(-kt)}$	*Zarein et al., 2013; Darvishi, 2012*
2	*Page*	$MR = e^{(-kt^n)}$	*Zarein et al., 2013; Darvishi, 2012*
3	*Henderson and Pabis*	$MR = ae^{(-kt)}$	*Zarein et al., 2013, Darvishi, 2012.*
4	*Modified Henderson and Pabis*	$MR = ae^{(-kt)} + be^{(-gt)} + c(e^{-ht})$	*Zarein et al., 2013; Sahari and Driscoll, 3013*
5	*Logarithmic*	$MR = aexp(-kt) + c$	*Zarein et al., 2013*
6	*Two-term*	$MR = ae^{(-k_0 t)} + be^{(-k_1 t)}$	*Sahari and Driscoll, 2013*
7	*Verma et al.*	$MR = ae^{(-kt)} + (1 - a)e^{(-gt)}$	*Karathanos, 1999; Darvishi, 2012.*
8	*Midilli et al.*	$MR = ae^{(-kt^n)} + bt$	*Zarein et al., 2013, Darvishi, 2012.*

The effective moisture diffusivity (D_e) of food materials characterizes their intrinsic property of mass and moisture transport including molecular diffusion, vapour diffusion, hydrodynamic flow and other mechanisms [2, 18]. Moisture transfer (water transport) during drying agricultural crops takes place through molecular diffusion, and was described using the solution term of the simplified Fick's second law of diffusion expressed in Equations (6a) and (6b) as [5, 6, 19]:

$$MR = \frac{M_t - M_e}{M_o - M_e} = \frac{8}{\pi} e^{\left(\frac{-\pi^2 D_e t}{L^2}\right)} \quad (6a)$$

$$ln(MR) = ln\frac{8}{\pi} - \frac{\pi^2 D_e t}{L^2} \quad (6b)$$

Where: MR = moisture ratio; D_e = effective moisture diffusivity ($m^2 s^{-1}$); L = half thickness of the sliced tomato samples (mm); t = drying time (mins).

The D_e was calculated, using the method of slopes as described by [5, 6, 19, 20]. A straight line was obtained when the logarithm of moisture ratio (ln MR) was plotted against drying time (t) for different temperatures and air velocities at constant slice thickness. The slope (coefficient k_1) of the regression line is related to the effective diffusion coefficient (D_e) of sliced tomato samples to be determined by substitution into Equation (7) as [19]:

$$k_1 = \frac{\pi^2 D_e}{4L^2} \quad (7)$$

The activation energy (E_a) was calculated by applying the drying constant (k_d) of the best fitted model to the Arrhenius as expressed in Equation (8) [1, 19]:

$$K_d = A_o e^{\left(-\frac{E_a}{R_g T_a}\right)} \tag{8}$$

The plots of the logarithm of the drying constant (ln K_d) against the reciprocal of the absolute drying temperature (T_a^{-1}) gave a linear function expressed as Equation (9) [6, 19]:

$$\ln K_d = \ln A_o - \frac{E_a}{R_g T_a} \tag{9}$$

Where: K_d = drying constant = effective moisture diffusion coefficient (m^2s^{-1}); A_o = pre-exponential factor (m^2s^{-1}); E_a = activation energy of diffusion of water ($kJmol^{-1}$); R_g = gas constant (8.3143 $kJmol^{-1o}K$); T_a = absolute temperature (°K).

Substituting the slope of the linear function, $k_2 = \frac{E_a}{R_g}$ into Equation (9) yields the activation of the slice tomato samples expressed as Equation (10):

$$E_a = k_2 . R_g \tag{10}$$

The coefficient of determination (R^2) of the model equation was obtained by fitting Equation (9) into the experimental data using linear regression (Minitab version 17). The thermodynamic properties of the drying process of tomato slice in a hybrid solar-electric crop dryer were determined through method described by [10, 11] expressed as Equations (11) to (13):

$$\Delta H = E_a - RT_a \tag{11}$$

$$\Delta S = R\left(\ln A_o - \ln\frac{K_B}{h_p} - \ln T_a\right) \tag{12}$$

$$\Delta G = \Delta H - T_a \Delta S \tag{13}$$

Where: ΔH = enthalpy variation ($Jmol^{-1}$); ΔS = entropy variation ($Jmol^{-1}K^{-1}$); ΔG = Gibbs free energy variation ($Jmol^{-1}$); K_B = Boltsmann constant (1.38 x 10^{-34} Js^{-1}); h_p = Planck constant (6.626 x 10^{-34} Js^{-1}); T_a = absolute temperature (°K).

Experimental procedure

Drying experiment was performed using a hybrid solar-electric convective dryer (Figure 1) designed and developed in the Engineering Workshop of Federal University of Technology, Owerri, Nigeria. A local variety of fresh tomato samples (*Gboko Spp.*) were procured from a rural market in Owerri, Imo State of Nigeria. The samples were washed and sliced into 10 mm thickness size using a sharp stainless steel knife and a vernier caliper with the direction of cutting perpendicular to the vertical axis of the tomato samples. The dryer heating unit (1500 W) was switched on, the required air flow and temperature were initiated by the 4 x 4 matrix keypad of the control unit. The drying chamber (with dimensions: 40 cm x 40 cm x 50 cm) was allowed to maintain steady-state condition. When the optimum preset drying temperature was attained, the arduino microprocessor automatically switches off the heating unit, and turns it on again when the drying chamber temperature falls one degree below the preset temperature. The dryer was programmed to operate at five different temperature thresholds of 50, 55, 60, 65 and 70°C, and at three varying air velocities (1.0, 1.5 and 2.0 ms^{-1}).

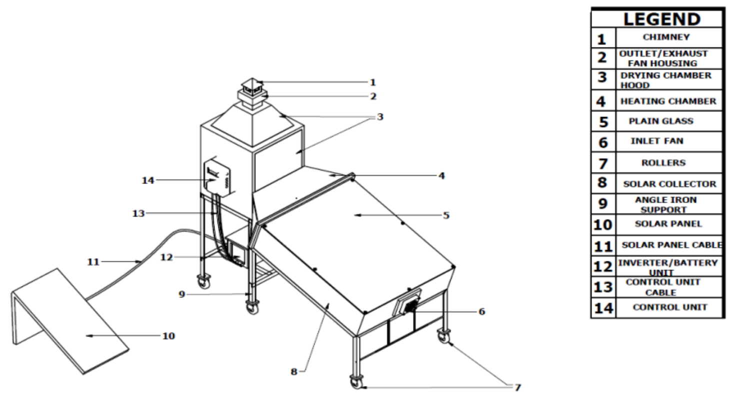


Figure 1. Isometric view of the hybrid drying system.

The initial mass of the 1 kg batch sliced samples was measured by a digital weighing balance (0.01 g, Camry instruments, China) and recorded, and placed on the drying racks in such a way that the drying air flows axially into the sample matrix (for faster drying). The initial moisture content of the samples was measured by drying 20 g of representative sliced sample in an oven dryer set at 105°C for 24 hours [8, 21, 22]. At every 30 minutes time interval, the control unit of the dryer system (consisting of arduino microprocessor) measures, records and displays on the screen, sample weight loss as well as the drying temperatures and relative humidities of the drying racks, chimney, solar collector, and ambient environment**.** The difference between the initial dried mass and the 30-minutes interval measured masses were used to calculate the moisture content at any time, t as well as the percentage weight loss for each dried batch. The weight losses were recorded by the use of a weight sensor attached to the weighing balance (with a precision of 0.01 g) in the drying chamber. The experiment was repeated for varying sample thicknesses, temperatures and air velocities for a batch of 1000 g. Drying was stopped when variation in the mass of tomato samples on the drying racks remained approximately constant, thus hygroscopic equilibrium was achieved. At this point moisture content decreased from 94.7% to 12.5% (w.b.).

RESULTS AND DISCUSSION

Modeling of drying curves

The kinetics of water desorption in tomato slices was investigated using the moisture content data (for 50, 55, 60, 65 and 70°C temperatures; 1.0, 1.5, and 2.0 ms^{-1} air velocities; and constant slice thickness of 10 mm) converted to moisture ratio using Equation (1b) and then fitted to the eight drying models (Table 1). Amongst the evaluated models, Midilli model showed the best fit to the experimental data of moisture ratio for all air velocity and temperature levels, having the highest mean values of R^2 of 0.9996 and lowest mean values of χ^2 (0.1814) and (0.00298) RMSE. The Midilli model had the highest value of R^2, and lowest values for χ^2 and RMSE at 2.0 ms^{-1} air velocity as shown in Table 2. At all temperature levels, the values obtained with the Midilli model satisfied the criterion for goodness of fit: highest value of R^2 (0.9999), lowest value of χ^2 = 0.1136, and lowest value of RMSE = 0.0212 at 70°C temperature and 2.0 ms^{-1} air velocity. The best fitted drying model describing the drying behaviour of sliced tomato samples (at air velocity of 2.0 ms^{-1} and temperature of 70°C) in a hybrid solar-electric dryer is therefore expressed as Equation (14):

$$MR_{tomato} = 4.926e^{(-0.8041t^{1.322})} + 0.007t \quad [R^2 = 0.9999] \quad (14)$$

Table 2. Statistical results obtained from the eight considered drying models at 2.0 ms^{-1} air velocity and varying drying temperatures.

Model name	***Temp. 50°C***			***Temp. 55°C***			***Temp. 60°C***		
	R^2	***χ^2***	***RMSE***	***R^2***	***χ^2***	***RMSE***	***R^2***	***χ^2***	***RMSE***
Lewis	*0.9987*	*2.5233*	*0.0242*	*0.9990*	*2.4218*	*0.0242*	*0.9996*	*2.4129*	*0.0218*
Page	*0.9959*	*0.6723*	*0.00692*	*0.9961*	*0.6719*	*0.00653*	*0.9973*	*0.6231*	*0.00601*
Henderson and Pabis	*0.9976*	*1.9273*	*0.0102*	*0.9981*	*1.9201*	*0.0100*	*0.9981*	*1.8407*	*0.00945*
Modified Henderson and Pabis	*0.9921*	*3.293*	*0.0197*	*0.9930*	*3.242*	*0.0181*	*0.9936*	*3.118*	*0.0174*
Logarithmic	*0.9985*	*0.8763*	*0.00722*	*0.9986*	*0.8701*	*0.00711*	*0.9989*	*0.8614*	*0.00703*
Two-term	*0.9955*	*0.7233*	*0.00726*	*0.9958*	*0.7015*	*0.00701*	*0.9962*	*0.6821*	*0.00631*
Verma et al.	*0.9961*	*2.649*	*0.0273*	*0.9961*	*2.602*	*0.0220*	*0.9966*	*2.531*	*0.0171*
Midilli et al.	***0.9993***	***0.2114***	***0.00438***	***0.9995***	***0.2106***	***0.00316***	***0.9997***	***0.1931***	***0.00281***
Model name	***Temp. 65°C***						***Temp. 70°C***		
	R^2	***χ^2***	***RMSE***				***RMSE***	***R^2***	***χ^2***
Lewis	*0.9993*	*2.3704*	*0.02133*				*0.9996*	*2.2014*	*0.0198*
Page	*0.9980*	*0.5831*	*0.00601*				*0.9987*	*0.5704*	*0.00549*
Henderson and Pabis	*0.9984*	*1.8114*	*0.00945*				*0.9989*	*1.7931*	*0.00724*
Modified Henderson and Pabis	*0.9941*	*2.504*	*0.0169*				*0.9944*	*2.894*	*0.0149*
Logarithmic	*0.9991*	*0.8401*	*0.00698*				*0.9994*	*0.8277*	*0.00684*
Two-term	*0.9966*	*0.6328*	*0.00622*				*0.9969*	*0.6014*	*0.00619*
Verma et al.	*0.9972*	*2.217*	*0.0136*				*0.9974*	*2.109*	*0.0149*
Midilli et al.	***0.9998***	***0.1783***	***0.00243***				***0.9999***	***0.1136***	***0.00212***

Equation (15) was validated by plotting the values of the predicted moisture ratios against those of the experimental and is presented in Figure 2. The high coefficient of determination (R^2 = 0.9998) which is close to unity, as well as the closeness of the points to the dotted lines indicate strong correlation or equality between the predicted and experimental values. Thus the suitability of the model to describe the drying behaviour of tomato slices in a convective hybrid solar-electric dryer. The behaviour of moisture ratio as a function of the drying time of tomato slices under the selected temperature levels at constant slice thickness is as shown in Figure 3.

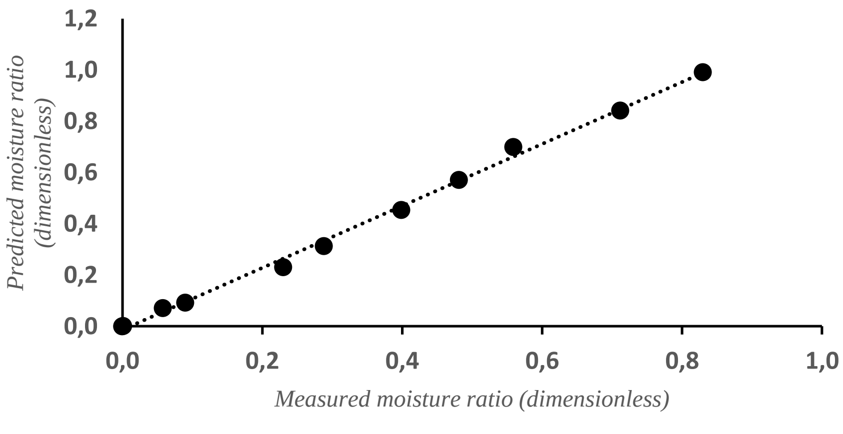


Figure 2. Predicted and experimental moisture ratio values for the Midilli model at 2.0 ms^{-1} and 70°C temperature.

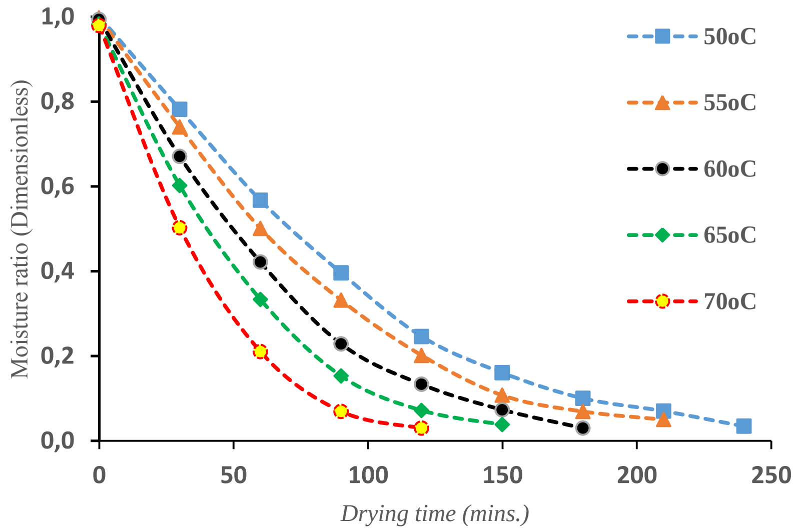


Figure 3. Drying curves of tomato slices described by Midilli et al. model at 2.0ms^{-1} and varying temperature levels.

However, in the context of thin-layer drying models, [16] evaluated the drying of tomato samples and found that the Midilli *et al.* model was the most suitable to describe the drying process at temperature range of 20, 40 and 60°C and at a constant air velocity of 2.0 ms^{-1}. Similarly, [23] in drying of lemon grass leaves observed that Midilli *et al.* model was the best in describing the drying process at a temperature range of 30 to 60°C. [24] found also that Midilli *et al.* was adequate in describing the drying process of Cumari do Para pepper (*Capsicum chinense Jacqui*) at temperatures of 45, 55 and 65°C. All these corroborated with the present study.

Figure 3 illustrates that the higher the drying temperature, the shorter the drying time. This is as a result of increased kinetic energy of internal water molecules to diffuse and evaporate at higher rates from the interior and surface of the products to the ambient air respectively. This thus, increases the drying rate and reduces the drying time. This is in agreement with the findings of [25], in thin-layer drying of jujube fruits; [19] in drying of ginger slices; [6, 19] for okra slices; [1] for tomato slices; [5] in drying of carrot slices. There is a sharper decrease in the moisture ratio at the beginning of the drying process, which could probably be as a result of the high initial moisture content of the tomato samples (94.7% w.b), which increases moisture loss. According to [26], this occurs when the moisture content of the product sample exceeds 80% w.b., the internal resistance to water transport is usually lower than the external resistance to moisture removal from the sample surface to ambient/drying air, which marks the constant rate period. Owing to that, there is internal resistance to moisture diffusion and the mechanism for controlling the drying process is by diffusion. [26, 27] suggest that in this drying period, the decreasing rate of the product internal moisture corresponds to the internal water migration that make up the drying kinetics.

The drying constants, K_d for the Midilli *et al.* model at different temperatures are given in Table 3. The natural logarithm of the drying constant, $\ln(K_d)$ is described as a function of the reciprocal of the absolute temperature, T_a^{-1} as presented in Figure 4. K_d increases in absolute values with temperature, due to greater heat transfer coefficient from the air to the product and, there is an increase in moisture diffusion to the product surface as a result of increased air velocity and temperature. The variations in the model parameters (a, n and b) are more related to mathematical fits than to a drying phenomenon, since Midilli is a semi-empirical model [26, 28].

Table 3. K_d-values of the fitted drying model for different temperatures.

Temperature (°C)	*Midilli et al. model*	R^2
50	$MR_{tomato} = 2.974e^{(-0.3074t^{1.202})} + 0.007t$	0.9993
55	$MR_{tomato} = 3.112e^{(-0.4011t^{1.196})} + 0.007t$	0.9995
60	$MR_{tomato} = 3.621e^{(-0.49918t^{1.22})} + 0.007t$	0.9997
65	$MR_{tomato} = 4.824e^{(-0.6083t^{1.282})} + 0.007t$	0.9998
70	$MR_{tomato} = 4.926e^{(-0.8041t^{1.322})} + 0.007t$	0.9999

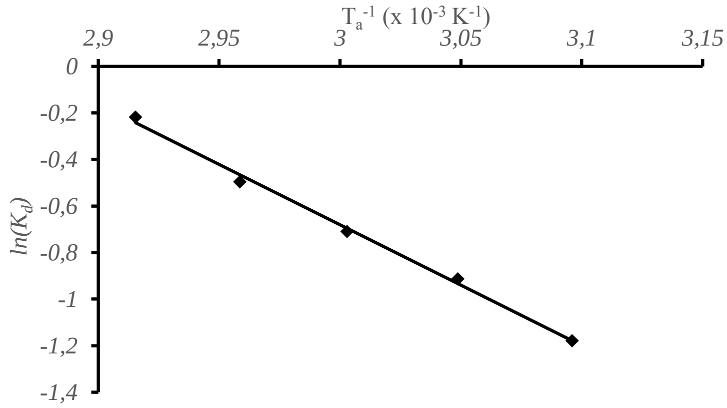


Figure 4. Arrhenius-type relationship between drying rate and absolute temperature of sliced tomato samples at constant air velocity and slice thickness.

The linear regression of the relationship between the logarithm of the drying constant and the inverse of the absolute temperature is expressed in Equation (15) as:

$$\ln K_d = 14.863 - \frac{5.1815}{T_a} \qquad [R^2 = 0.9967] \qquad (15)$$

The high R^2-value (0.9967) indicates strong correlation between the parameters of the linear regression function. The moisture diffusivity, D_e was calculated by substituting the values of Equation (7) into Equation (6b) and presented in Table 4. From Figure 4, the Arrhenius expression (Equation 8) can be written as:

$$K_d = 724328.28 \exp\left(\frac{38382.22}{8.3143T_a}\right) \qquad (16)$$

Table 4. Effective moisture diffusivity (D_e) of tomato slices in different drying temperature and constant air velocity and sample thickness.

Air velocity (ms^{-1})	*Diffusion coefficient (m^2s^{-1})*				
	50°C	*55°C*	*60°C*	*65°C*	*70°C*
1.0	$4.9541x10^{-9}$	$5.4729\ x10^{-9}$	$5.9156\ x10^{-9}$	$6.3817\ x10^{-9}$	$6.8153\ x10^{-9}$
1.5	$5.1495\ x10^{-9}$	$5.8182\ x10^{-9}$	$6.2457\ x10^{-9}$	$6.5041\ x10^{-9}$	$7.1163\ x10^{-9}$
2.0	$5.2364\ x10^{-9}$	$6.1922\ x10^{-9}$	$6.3343\ x10^{-9}$	$6.9932\ x10^{-9}$	$7.5726\ x10^{-9}$

The D_e values fall within the reported range for vegetables and other food materials [6, 13, 16, 17, 29, 30, 31]. Moisture diffusivity was affected by the drying temperature and air velocity: D_e values increased with increasing air temperature due to decrease in vapour pressure in the product matrix [32, 33]. The minimum value of D_e ($4.9541x10^{-9}$ m^2s^{-1}) was found at the minimum temperature, while at constant temperature values an increase in the air velocity increased D_e values probably because at a low air velocity (say $0.1ms^{-1}$), the drying air may had better contact with the sample surface but the rate of its heat and mass transfer was low as to necessitate greater absorption of moisture which results in decreased moisture diffusivity.

Similar observations were reported by other researchers for carrot, berberis fruit, red chillies, apples, okra, ginger, tomato, bell pepper, melon, and field pumpkin [1, 2, 13, 14, 15, 17, 19, 30, 34, 35, 36].

The slope of Figure 4 provides the relationship between E_a and R_g, whereas the intersection with the $\ln(K_d)$-axis indicates the A_o-values. Table 5 shows that E_a-values and their corresponding R^2 and the pre-exponential factor values of the sliced tomato samples are within the range of E_a-values for food materials (12.7 to 110 $kJmol^{-1}$) as reported by [1, 5, 14, 19].

Table 5. Activation energy, pre-exponential factor and R^2-values of tomato slices at varying air velocities.

Air velocity (ms^{-1})	**E_a ($kJmol^{-1}$)**	**R^2**	**A_O x 10^{-3} (m^2s^{-1})**
1.0	40.96	0.9692	8.62
1.5	39.21	0.9703	7.07
2.0	37.86	0.9734	6.31
Mean	**39.342**	**0.971**	**7.333**

From Table 5, the activation energy, E_a of sliced tomato samples decrease with increasing air velocity. The E_a-values obtained from this present study are within the range (33.33 to 43.23 $kJmol^{-1}$) obtained by [16] for similar air velocity and temperature ranges. The high E_a-values were as a result of the relatively small amount of water removed by the thermal energy of the drying air. Activation energy is the energy barrier that must be overcome in order to initiate moisture diffusion. By increasing the temperature and drying rate (air flow), this energy barrier can be easily overcome but there should be a compromise between drying temperature and acceptable product quality [13]. Increasing the air velocity (at increased temperature) speeds up the rate of surface moisture evaporation, and most importantly increases the heat transfer rate which in turn increases the kinetic energy of the internal moisture for rapid collision, hence reduced activation energy. The mean E_a-value obtained from Figure 4 at varying air velocities was 38.38 $kJmol^{-1}$. Correa *et al.* [37] corroborated that the lower the E_a, the higher will be the water diffusivity in the product sample, i.e., the lower will be the energy necessary for physical transformation to occur, which refers to the transformation of liquid free water to vapour (drying). Similar observations were reported in the works of [6, 13, 16, 17] for sliced food materials.

Thermodynamically, E_a is defined as the ease with which water molecules surpass the energy barrier during internal moisture diffusion [26, 38]. The thermodynamic properties of sliced tomato drying were determined using Equations (11) to (13), and presented in Table 6.

Table 6. Thermodynamic properties of dried sliced tomato.

Temperature (^oC)	***ΔH ($Jmol^{-1}$)***	***ΔS ($Jmol^{-1}$)***	***ΔG ($Jmol^{-1}$)***
50	*35695.45*	*-64.14*	*14968.61*
55	*35653.88*	*-64.05*	*14635.87*
60	*35612.31*	*-63.89*	*14327.36*
65	*35570.74*	*-63.77*	*14006.34*
70	*35529.17*	*-63.65*	*13687.67*

Enthalpy decreased with increasing temperature, implying a lower energy requirement for drying of sliced tomato at higher drying temperatures. The positive values of the enthalpy, ΔH indicate that the drying process is an endothermic reaction, which requires addition or supply of energy in the form of heat for the physico-chemical transformations to occur. As the temperature of the drying chamber increased, entropy of the system also decreased; indicating increase in the order of the system, which is entropically unfavourable [26].

Some researchers [26, 39] suggest that a substance such as water can have only entropy if the degrees of freedom of the movement of translation or rotation are lost. Gibbs free energy (free enthalpy) is a thermodynamic potential of a system that can be considered as a measurement of maximum reversible work performed by a thermodynamic system in the process of moisture adsorption or desorption (i.e., moisture gain or loss) [26, 40]. According to Costa *et al.* [26], Gibbs energy provides clearer understanding of the thermodynamic driving forces that affect reactions.

However, in the drying of tomato slices, the effect of enthalpy was evident; which decreased with increasing drying temperatures, with its maximum (14968.61 kJmol^{-1}) corresponding with the minimum temperature (50^{o}C) and its positive values indicating endergonic reactions: supply of heat energy from the ambient environment – drying chamber, in which the sliced samples are kept for heat and mass reactions to occur.

CONCLUSION

Thin-layer mathematical modeling and determination of thermodynamic properties of sliced tomato samples during hot air drying in a hybrid solar-electric dryer were investigated at five different drying temperatures (50, 55, 60, 65 and 70^{o}C), three different air velocities (1.0, 1.5 and 2.0 ms^{-1}), and at a constant slice thickness (10 mm). The following results were obtained as summarized below:

1. According to statistical analyses applied to the eight selected models, the Midilli et al. model gave the best fit to the experimental data of drying of tomato slices with the highest value of R2 (0.9999), lowest value of χ^2 = 0.1136, and lowest value of RMSE = 0.0212 at 70oC temperature and 2.0 ms-1 air velocity.
2. The model equation is expressedas: $MR_{tomato} = 4.926e^{(-0.8041t^{1.322})} + 0.027t$
3. The drying constant increased with increases in drying temperature. Temperature and air velocity influenced both moisture diffusivity and activation energy. The value of moisture diffusivity increased with increase in temperature and air velocity. The highest effective moisture diffusivity was observed at air velocity of 2.0 ms-1 and temperature of 70oC, whereas it was lowest at air velocity of 1.0 ms-1 and temperature of 50oC.
4. The activation energy of sliced tomato decreased with air velocity. The mean activation energy required to drying 1kg batch of 10 mm sliced tomato samples in a hybrid solar-electric dryer is 39.34 kJmol-1.
5. The effects of different drying temperatures on the thermodynamic properties of dried tomato slices such as enthalpy, entropy and, Gibbs free energy were studied. Enthalpy and Gibbs free energy decreased with increase in temperature, as well as entropy which exothermically decreased with increasing temperature.

Further studies on optimization of the drying process and determination of thermodynamic properties of different varieties of sliced fruits and vegetables at varying air velocities, sample thicknesses and drying temperatures using different drying systems are recommended. Experimental investigation on the heat and mass transfer parameters as well as the thermal utilization efficiency and dried product quality assessment of various species of sliced vegetables, roots and tuber crops using any solar-assisted hybrid dryer with a heat recovery unit is of great importance for future work.

REFERENCES

[1] Abano, E.E.; Ma, H.; Qu, W. 2011. Influence of air temperature on the drying kinetics and quality of tomato slices. *Food Processing and Technology,* 2(5), pp.1-9.

[2] Dianda, B.; Ousmane, M.; Kam, S.; Ky, T; Bathiebo, D.J. 2015. Experimental study of the kinetics and shrinkage of tomato slices in convective drying. *African Journal of Food Science,* 9(5), pp. 262-271.

[3] Mu'azu, K.; Bugaje, I.M.; Mohammed, I.A. Performance evaluation of forced air-convection vegetable drying system. *Journal of Basic and Applied Scientific Research* 2012, *2(3*), pp. 2562–2568.

[4] Idah, P.A.; Obajemihi, O.I.; Adeboye, O.A.; Olaniyan, A.M. 2014. Assessment of osmotic pre-drying treatment on drying rates of fresh tomato fruits. *Nigerian Journal of Technological Development,* 11(1), pp. 22 – 26.

[5] Doymaz, I. 2004a. Convective air drying characteristics for thin-layer carrots. *Journal of Food Engineering,* 61(3), pp.359-364.

[6] Doymaz, I. 2004b. Drying characteristics and kinetics of okra. 69(2005), pp.275-279.

[7] Darvish, H. 2012. Energy consumption and mathematical modeling of microwave drying of potato slices. *Agricultural Engineering International*, CIGR Journal, 14(1), pp. 94- 102.

[8] Darvishi, H.; Asi, R.A.; Asghari, A.; Najafi, G.; Gazori, H.A. 2013. Mathematical modeling, moisture diffusion, energy consumption and efficiency of thin-layer drying of potato slices. *Journal of Food Process Technology*, 4 (3), pp. 215 - 229.

[9] Sahari, Y.; Driscoll, R. H. 2013. Thin layer drying of agricultural products: a review. Malaysian Postgraduate Conference, pp., 8-21.

[10] Costa, C.F.; Correa, P.C.; Vanegas, J.D.B. 2016. Matematical modeling and determination of thermodynamic properties of jabuticaba peel during the drying process, Revista Brasileira de Engenharia Agricola e Ambiental, 20(6), pp.576-580.

[11] Jideani, V.A.; Mpotokwana, S.M. 2009. Modeling of water absorption of Botswana Bambara varieties using Peleg's equation, *Journal of Food Engineering*, 92, pp.182-188.

[12] Oliveira, D.E.C.; Resende, O.; Chaves, T.H.; Souza, K.A.; Smaniotto, T.A.S. 2014. Proriedades termodinamicas das sementes de pinhaomanso. *Bioscience Journal,* 30, pp.147 – 157.

[13] Afolabi, T.J.; Agarry, S.E. 2014. Thin layer drying kinetics and modelling of okra (*Abelmoschus Esculentus L.*) slices under natural and forced convective air drying. *Food Science and Quality Management*, 28, pp.30-44.

[14] Sadin, R.; Chegini, G.; Khodadadi, M. 2017. Drying characteristics and modeling of tomato thin layer drying in combined infra-red hot air dryer. *Agricultural Engineering International,* CIGR E-Journal, 19(1), pp.150 – 157.

[15] Aghbashlo, M.; Kianmehr, M.H.; Samimi-Akhijahani, H. 2008. Influence of drying conditions on the effective moisture diffusivity, energy of activation and energy consumption during the thin-layer drying of beriberi fruit (Berberidaceae). *Energy Conversion and Management,* 49, pp.2865–2871.

[16] Taheri-Garavand, A.; Rafieea, S.; Keyhania, A. 2011a. Mathematical modeling of thin layer drying kinetics of tomato influence of air dryer conditions. International Transaction *Journal of Engineering, Management and Applied Sciences and Technologies,* 2*(2), pp.147-160.*

[17] Taheri-Garavand, A.; Rafieea, S.; Keyhania, A. 2011b. Study on effective moisture diffusivity, activation energy and mathematical modeling of thin layer drying kinetics of bell pepper. *Australian Journal of Crop Science*, 5(2), pp.128-131.

[18] Abbaszadeh, A.; Motevali, A.; Ghobadian, B. 2012. Effect of air velocity and temperature on energy and effective moisture diffusivity for Russian Olive (*Elaeagnusan gastifolial L.*) in thin layer drying. *Iran Journal of Chemical Engineering*, 31(1), pp.75-79.

[19] Afolabi, T.J.; Akintunde, T.Y.; Oyelade, O.J. 2014. Influence of drying conditions on the effective moisture diffusivity and energy requirements of ginger slices. *Journal of Food Research,* 3(5), pp.103 – 112.

[20] Zielinska, M.; Markowski, M. 2010. Air drying characteristics and moisture diffusivity of carrots. *Chemical Engineering and Processing,* No 49: pp.212-218.

[21] Association of Official Agricultural Chemists, (AOAC) Int. Maryland, USA, 2005, P.4.

[22] Koyuncu, T.; Tosun, I.; Pinar, Y. 2007. Drying characteristics and heat energy requirement of cornelian cherry fruits (*Cornus mas L.*). *J. of Food Eng.*, 78(4), pp. 735 – 739.

[23] Martinazzo, A. P.; Corrêa, P. C.; Resende, O.; Melo, E. De, C. 2007. Análise e descrição matemática da cinética de secagem de folhas de capim-limão. *Revista Brasileira de Engenharia Agrícola e Ambiental,* 11, 301-306. http://dx.doi.org/10.1590/ S1415-43662007000300009

[24] Reis, R. C.; Barbosa, L. S.; Lima, M. de L.; Reis, J. de S.; Devilla, I. A.; Ascheri, D. P. R. 2011. Modelagem matemática da secagem da pimenta Cumari do Pará. *Revista Brasileira de Engenharia Agrícola e Ambiental,* 15. pp.347-353.

[25] Motevali, A.; Abbaszadeh, A.; Minaei, S.; khostaghaza, M.H.; Ghobadian, B. 2012. Effective moisture diffusivity, activation energy and energy consumption in thin-layer drying of jujube (*Zizyphus jujube Mill). J.of Agr. Science and Technology,* 14, pp.523-532.

[26] Costa, L. M.; Resende, O.; Gonçalves, D. N.; Oliveira, D. E. C. de. 2015. Modelagem matemática da secagem de frutos de crambe em camada delgada. *Bioscience Journal,* 31, pp. 392-403.

[27] Oliveira, R. A. de; Oliveira, W. P. de; Park, K. J. 2006. Determinação da difusividade efetiva de raiz de chicória. *Engenharia Agrícola,* 26,181-189.

[28] Midilli, A.; Kucuk, H.; Yapar, Z. 2002. A new model for single-layer drying. *Drying Technology,* 20, pp. 150-160.

[29] Doymaz, I. 2005. Drying Behaviour of Green Beans. *Journal of Food Engineering*, 69, pp. 161-165.

[30] Aghbashlo, M.; Kianmehr, M.H.; Khani, S.; Ghasemi, M. 2009. Mathematical modelling of thin-layer drying of carrot, *International Agro physics,* 23, 313-317.

[31] Honore, O.K.; Francois, Z.; Raguilignaba, S. 2014. Characterization of okra convective drying, influence of maturity. *Food and Nutrition Sciences,* 5, pp. 590 – 597.

[32] Nwakuba, N.R.; Asoegwu, S.N; Nwaigwe, K.N. 2016a. Energy consumption of agricultural dryers: an overview. *Agricultural Engineering International: CIGR Journal*, 18(4), pp. 119-132.

[33] Nwakuba, N.R.; Asoegwu, S.N.; Nwaigwe, K.N. 2016b. Energy requirements for drying of sliced agricultural products: a review. *Agricultural Engineering International: CIGR Journal,* 18(2), pp. 144-155.

[34] Meisami-asl, E.; Rafiee, S.; Keyhani, A.; Tabatabaeefar, A. 2010. Drying of apple slices and effect on moisture diffusivity and activation energy. Plant Omics Journal, 3(3), pp. 97-102.

[35] Azadbakht, M.; Darvishi, H.; Rezaeiasl, A.; Asghari, A. 2012. Thin layer drying characteristics and modelling of melon slices (Cucumismelo). *Journal of Agricultural Technology,* 8(6), pp. 1867-1880.

[36] Olurin, T.O.; Adelekan, A.O.; Olosunde, W.A. 2012. Mathematical modelling of drying characteristics of balanced field pumpkin (*Cucurbita pepo L*) slices. *Agricultural Engineering International: CIGR E-Journal,* 14(4), pp. 246-254.

[37] Corrêa, G. C.; Oliveira, G. H. H.; Botelho, F. M.; Goneli, A. L. D.; Carvalho, F. M. 2018. Modelagem matemática e determinação das propriedades termodinâmicas do café (*Coffea arabica* L.) durante o processo de secagem. Revista Ceres 2010, 57, 595-601. http:// dx.doi.org/10.1590/S0034-737X2010000500005 (accessed January 15, 2018).

[38] Resende, O.; Ferreira, L. U.; Almeida, D. P. 2010. Modelagem matemática para descrição da cinética de secagem do feijão azuki (Vigna angularis). *Revista Brasileira de Produtos Agroindustriais*, 12, 171-178. http://dx.doi.org/10.15871/1517-8595/rbpa.

[39] Dannenberg, F.; Kessler, H. 1988. Reaction kinetics of the denaturation of whey proteins in milk. *Journal of Food Science*, 53, pp. 258-263.

[40] Kaleemullah, S.; Kailappan, R. 2007. Monolayer moisture, free energy change and fractionation of bound water of red chillies. *Journal of Stored Products Research*, 43, pp. 104-110.

MODELI I TERMODINMAČKE OSOBINE TANKIH KRIŠKI PARADAJZA SUŠENOG VRELIM VAZDUHOM

Nnaemeka Nwakuba[1], Osita Chukwuezie[2], Sabbas Asoegwu[3], Godfrey Nwandikom[3], Ngozi Okereke[3]

[1]*Odsek za poljoprivredno inžinjerstvo i resurse, Michael Okpara Poljoprivredni Univerzitet, Umudike, P.M.B. 7267 Umuahia, Abia, Nigeria.*
[2]*Odsek za poljoprivredno inžinjerstvo i životnu sredinu, Imo State Polytechnika, Umuagwo, P.M.B. 1472, Imo, Nigeria.*
[3]*Odsek za poljoprivredno inžinjerstvo i resurse, Federalni Univerzitet za tehnologiju, P.M.B. 1526 Owerri, Imo, Nigeria.*

✧

Sažetak: Prikazana je kinetika sušenja i određivanje termodinamičkih osobina uzoraka narezanog paradajza tokom sušenja toplim vazduhom u solarnoj sušari. 1 kg svežih uzoraka paradajza su rezane na debljinu 10 mm i sušene na različitim brzinama vazduha (1,0, 1,5 i 2,0 ms^{-1}) i temperaturama (50, 55, 60, 65 i 70 °C) hibridnim načinom sušenja. Da bi se izabrao najbolji model sušenja, urađeno je 8 tanko-slojnih matematičkih modela sa eksperimentalnim podacima. Visoke vrednosti koeficijenta determinacije, R2 i male vrednosti smanjene sume kvadrata greške (SSE) i kvadratne greške (RMSE) ukazuju da su Midilli i sar. model adekvatno opisali proces sušenja narezanog paradajza, sa najvišim R2 (0.9999), najnižim SSE (0.1136) i najnižom vrednosti RMSE (0.0212) pri temperaturi od 70°C i brzinom vazduha 2.0 ms^{-1}. Arrenius model predstavlja konstantu sušenja kao funkciju temperature. Efikasna difuzivnost vlage se pove ava sa pove anjem temperature i brzine vazduha; sa najve om vrednoš u dobijenom brzinom vazduha od 2,0 ms^{-1} i temperaturom od 70^{o}C, dok je bila najmanja brzina vazduha od 1,0 ms^{-1} i temperatura od 50^{o}C. Srednja energija aktivacije koja je potrebna za sušenje 1kg šarže od 10 mm rezanih uzoraka paradajza bila je 39,34 $kJmol^{-1}$. Utvrđeno je da se smanjuju vrednosti slobodne energije Enthalpy i Gibbs sa pove anom temperaturom sušenja, kao i entropijom koja je takođe ekzotermno smanjena sa temperaturom. Navedene su preporuke za dalje istraživanje.

Ključne reči: termodinamička osobine, kinetika sušenja, rezanci paradajza, desorpcija vode, energija aktivacije.

Prijavljen: *Submitted*:	26. 03. 2018.
Ispravljen: *Revised*:	01.04.218
Prihva en: *Accepted*:	04.04.2018

CIP Каталогизација у публикацији
Народна библиотека Србије, Београд
631(059)
ПОЉОПРИВРЕДНА техника : научни часопис = Agricultural Engineering : Scientific Journal / одговорни уредник Мићо В. Ољача – Год. 1, бр. 1 (1963)- . - Београд; Земун : Институт за пољопривредну технику, 1963- (Београд : Штампарија : Пољопривредни факултет, Немањина 6, 11080 Земун) . – 25 cm
Тромесечно. – Прекид у излажењуод 1987-1997. године
ISSN 0554-5587 = Пољопривредна техника
COBISS.SR-ID 16398594