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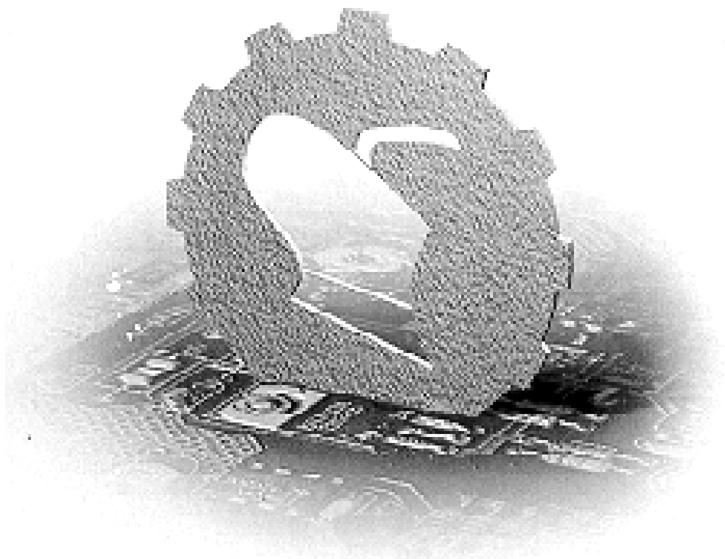

УНИВЕРЗИТЕТ У БЕОГРАДУ, ПОЉОПРИВРЕДНИ ФАКУЛТЕТ,
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THE IMPORTANCE OF INTRODUCING A DIRECT FOOD DISTRIBUTION MANUFACTURED BY AGRICULTURAL PRODUCTION IN A SINGLE ECONOMY

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Summary: The agricultural sector should be organized in such a way that agricultural products that create highways in the form of production and sale of food should be supplied through direct food supply distribution chains. In addition, the food distribution system should target food produced and sold locally, which has gained increasing importance over the last three decades. Thus, agrarian observation enables fierce market competition, high distribution and logistics costs, as well as small individual size of shipments, etc. Using agricultural business modeling and design approaches requires new aspects of innovative logistics and modern information and communication technologies. All this makes it possible to evaluate and evaluate different ways of distributing food. This paper draws attention to the importance of the direct model as a channel of distribution and access in the organization of agriculture as an activity. After that, it is possible to make precise analyzes that can be used to refine the model of business processes with the formation of various ways of food distribution.

Key words: *short food supply chain; distribution; sustainability; information and communication technology; business process modelling*

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INTRODUCTION

The supply of food that is the product of agricultural activity should respect the principles of sustainability (economic, environmental and social) and provide progressive opportunities for them. The basis of modeling that will enable the adoption of such a way of managing agriculture that will be in line with the economic strengthening of the country.

Modeling food management and its distribution should take into account the network through which products move from the point of production to the consumer, with a minimum number of intermediaries.

This leads to a decrease in the number of road users, a decrease in the brokerage fee, with easier control over the sale price, but also the existence has a positive impact on the employment rate.

In addition to the directly visible impact, there is also the impact of strengthening the sense of power of the agricultural sector towards a sustainable society and influencing the social development of the region while preserving local communities and social justice, especially in rural areas. Finally, there is an impact on environmental criteria.

Thus the concept of creation of agricultural observation [1], [2], [3], [4], [5] and products of agriculture in the form of food [6], [7], [8], [9], [10] which is heterogeneous distribution methods [11], [12], [13] and which [14] is delivered to a large number of consumers [15].

THE IMPORTANCE OF AGRICULTURAL MANAGEMENT IN THE PROCESS OF FOOD DISTRIBUTION

Management of agriculture should be seen as management associated with the distribution of food, as well as the existence of a justification for the costs of the implementation of logistics activities, while respecting regulated and complicated legal provisions.

Accordingly, modern management respects contemporary logistical trends (digitization, cost reduction, improving flexibility and reactivity to customer demand, etc.), while respecting the specific context of the distribution of locally produced food in the sovereign market.

Technological advances in information and communication technologies should be accompanied by appropriate business models as a reflection of innovative logistics strategies and changes in the logistics management paradigm that can be applied in agriculture, that is, in food production and food distribution in the territory of a country.

The basis for this study is finding an effective solution for the state-level food distribution system, that is, a food distribution system that can be implemented in the Republic of Serbia.

The focus of such modeling in the work has been put by the author on direct supply as a distribution channel.

A MODEL THAT TAKES INTO ACCOUNT THE FACTORS AFFECTING CUSTOMERS IN THE OBSERVED DISTRIBUTION SYSTEM

Finding a practical model of behavior requires the application of a number of factors that influence the formation of a distribution chain. In this paper, the authors present the following important factors of influence on the customer as key points of the distribution system.

The presentation is given in Figure # 1 by the author and presents possible ways of organizing and influencing the customer as a key category of observation, respectively, by categorizing the impact on customers that are a key category of observation in the food distribution system in the Republic of Serbia.

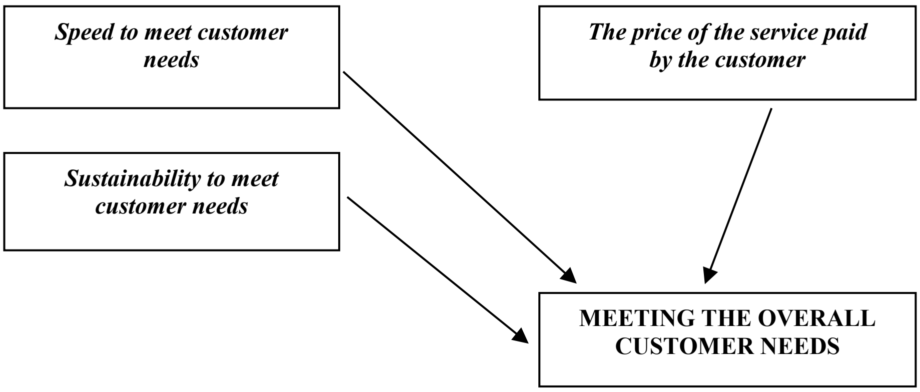

Fig. 1. Meeting the needs of customers who are the focus of interest of food distribution companies

INNOVATIVE LOGISTICS SOLUTIONS AS A PRODUCT OF THE SUPPLY CHAIN MANAGEMENT STRATEGY

When defining a supply chain management strategy, companies are confronted with a number of limiting factors that result from the changes that are happening in the global economic environment.

These changes, in the form of new trends, affect the business strategy, which directly depends on the choice of strategy to be applied by the companies dealing with the organization of food distribution in a particular market.

The authors illustrate possible solutions that will implement innovations in the logistics approach to food distribution through the illustrations in Figure 1.

DIRECT SUPPLY - SHORT SUPPLY CHAIN

A short food supply chain, commonly referred to in the literature as a direct or local food supply chain, can be identified by two basic characteristics: A direct food supply means "production, processing, sale and consumption of food takes place in a relatively small geographical area (territory) the number of intermediaries (or intermediaries) in the chain is minimal '.

Such supply is defined as a "short supply chain", when short distances or only a few intermediaries exist between producers and consumers.

This management aims to reduce the number of intermediaries in their economic endeavor to make the manufacturer make a greater share of the profits than the production in which he or she performs economic.

BASIC CHARACTERISTICS OF DIRECT FOOD SUPPLY CHANNELS

There are numerous peculiarities related to the direct food supply channels in the logistics process and this way of observing the organization.

The authors point out the most important three factors that should be taken into account in the process of considering the direct way of food supply in the Republic of Serbia.

The essential characteristics of the outlined supply model would be:

1. Direct communication between producer and consumer,
2. Local existence in the local market
3. Selling in addition to local buyers.

RESPECT FOR THE FOOD DISTRIBUTION CHANNEL ENVIRONMENT

The authors provide a possible overview that points to the observation and importance of the environment from the impact on the consumer as a target category, which is the focus of all movements in the form of tracking the product from the moment of creation to the moment when it is offered for sale.

The authors illustrate the importance and the impact on the consumer of the environment by presenting the number 2 image.

This implies that the environment influences changes in business and competitive strategies, which is ultimately the result of changes in strategy that will be implemented by new and innovative logistics in the distribution of food in the country by companies primarily engaged in agricultural business.

A MODEL THAT ENABLES SHORT DISTRIBUTION OF AGRICULTURAL PRODUCTS

A model that includes agricultural operators as well as consumers on the other hand who is the focus of research and allows for the short distribution of agricultural products is shown in Fig. 1 by the author.

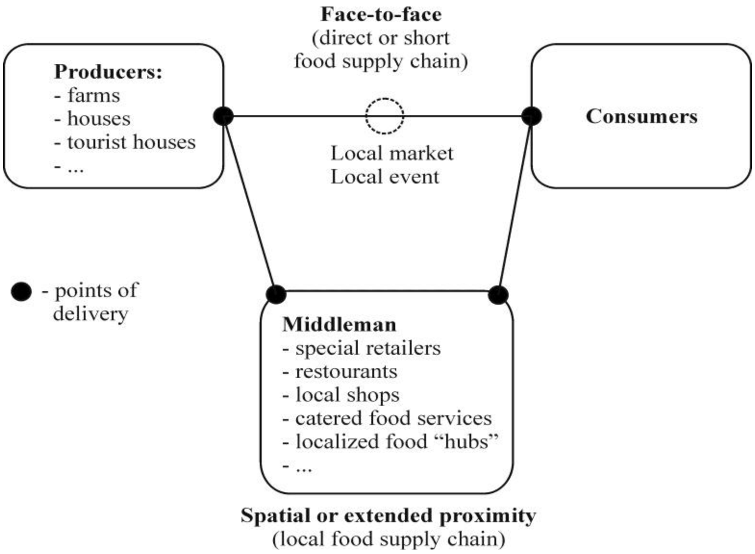

Fig. 2. Model of short distribution of feed in the Repbulic of Serbia

DISCUSSIONS

The formation of a possible sustainable model of an efficient logistics system in agriculture is crucial for the development of a logistical food distribution system in a country's economy.

In this paper, the authors draw attention to the existence of a direct model by which applications can be implemented in the real business of a large number of individual entities.

The authors have presented models by which it is possible to create the development and improvement of logistical resources and competencies of food producers.

This can, with the use of logistical capacities, make a real functioning of the food distribution system and provide the satisfaction of basic and desired customer needs.

CONCLUSION

In this paper, the authors draw attention to the use of a possible applicable food distribution model in a country that seeks to meet the needs of customers to purchase food under acceptable general conditions.

The authors provided a direct acceptable model of food supply. This model may be the basis for future research into those that aim to engage in direct food distribution with some of the innovations in food distribution and customer satisfaction.

However, there are limitations to the application of the model. Let's just point out: a small concentration that can mean delivering small amounts of food in this way of food distribution.

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ZNAČAJ UVOĐENJA DIREKTNOG KANALA DISTRIBUCIJE HRANE PROIZVEDENE OD STRANE POLJOPRIVREDNE PROIZVODNJE U JEDNOJ EKONOMIJI

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Sažetak: Poljoprivredni sektor treba da se organizuje tako da produkti poljoprivredne delatnosti koji stvaraju autpute u vidu proizvodnje i prodaje hrane treba da se organizuju putem korištenja direktnih lanaca distribucije snabdevanja hrane. Osim toga, sistem distribucije hrane treba da bude usmeren na hranu koja se proizvodi i prodaje lokalno, a koja dobija sve veći značaj u poslednje tri decenije. Tako posmatranje agrara omogućava oštru tržišnu konkurenciju, postojanje visokih troškova distribucije i logistike, kao i malu pojedinačnu veličinu pošiljki itd. Koristeći pristupe modeliranja i projektovanja poslovanja od poljoprivrednih preduzeća se zahteva primena novih aspekata inovativnog načina logistike koji pretpostavljaju primenu savremenih informacionih i komunikacionih tehnologija. Sve to omogućava ocenu i procenu različitih načina distribucije hrane. Ovaj rad, skreće pažnju na značaj korištenja modela direktnog kanala distribucije hrane. Nakon toga, moguće je sačiniti precizne analize pomoću kojih će se moći usavršiti prikazani modela distribucije hrane.

Ključne reči*: kratak lanac snabdevanja hranom; distribucija; održivost; informaciono-komunikaciona tehnologija; modeliranje poslovnih procesa*

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AUTOMATSKI UREĐAJ ZA PRIHRANU DOMAĆIH I DIVLJIH ŽIVOTINJANA NA PAŠNJACIMA

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Sažetak: U radu je prikazan prototip automatskog uređaja za prihranu domaćih i divljih životinja u organskom i slobodnom uzgoju na pašnjacima. Prikazan je jednostavan uređaj za prihranu domaćih i divljih životinja koji ima potpuno autonoman rad čak i do 60 dana u zavisnosti od broja životinja koje se hrane. Napajanje elektromotora elektičnom energijom se može ostvariti iz mreže i iz fotonaponskih ćelija max 100 W. Proces doziranja hrane iz kontejnera se može obaviti jednom ili vše puta dnevno. Količina hrane koje se dodaje može da se podešava svakoga dana i dozira, odnosno povećava ili smanjuje tokom vremena u zavisnosti od stanja i količine raspoložive kabaste hrane na pašnjaku i potrebe životinja. Ispitivanja rada uređaja u eksploataciji sprovedeni su na porodičnom poljoprivrednom gazdinstvu gde su krave provele jedan deo godine na pašnjaku. Praćenje rada uređaja za prihranu životinja na otvorenom polju obavljeno je u vremenskom periodu od maja do oktobra meseca. Rezultati ispitivanja pokazuju visoku pouzdanost i potpunu samostalnost u radu automatskog uređaja za prihranu domaćih i divljih životinja i da se kao takav može primeniti u organskom, ekološkom i slobodnom uzgoju na pašnjacima.

Ključne reči: *slobodan uzgoj životinja, ishrana, automatska hranilica*

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Rad je deo aktivnosti projekta “Unapređenje biotehnoloških postupaka u funkciji racionalnog korišćenja energije, povećanja produktivnosti i kvaliteta poljoprivrednih proizvoda“, broj TR 31051, Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije.

UVOD

Slobodan uzgoj zasušenih krava, tov junadi, konja i dr. na pašnjacima predstavlja veliki potencijal u Srbiji koji još uvek nije dovoljno iskorišćen. Raseljena sela, napuštena domaćinstva, nepregledne livade i pašnjaci pružaju veliku mogućnost ishrane životinja na paši i unapređenju, ekološke i organske proizvodnje mesa.

Organska proizvodnja i slobodan način uzgoja predstavljaju držanje stoke na pašnjacima pod otvorenim nebom u prirodnim uslovima, gde životinje borave na pašnjacima, šumama i hrane se svežom kabastom hranom [3]. Na taj način goveda, ovce, koze, konji uspešno održavaju određene površine u pogledu biljnih populacija, pre svega sprečavanja razvoja korova, samoniklog rastinja, paprati i dr. Organska stočarska proizvodnja se brže razvija kod preživara, jer je ishrana životinja bazirana na pašnjacima i kabastoj hrani [5], [8].

Na komercijalnim farmama kod vezanog ili slobodnog načina gajenja goveda, životinje se hrane sa kompletnim mešanim obrokom TMR (Total mixed ration) u kojem se nalazi seno, silirana kabasta hrana i koncentrovana smeša. Priprema i distribucija TMR obroka u jasle obavlja se mikser distributer prikolicama sa horizontalnim i vertikalnom spiralom za mešanje hrane [9], [1], [2], [7].

Slobodan način gajenja goveda na pašnjacima je dosta zastupljen u zemljama sa razvijenom govedarskom proizvodnjom (Holandija, Danska, Engleska, Švjacarska, Nemačka). U Srbiji ovaj način gajenja ima sezonski karakter i vrlo malo je zastupljen sa svega 6,1%. Period ispaše na pašnjacima je sezonski i najčešće traje pet-šest meseci od maja do oktobra meseca [6], [4].

U toku trajanja slobodnog tova goveda zbog vegetacionog perioda travnjaka dolazi do variranja, (povećanja i smanjenja) raspoložive zelene mase, dok dužinom tova rastu potrebe za hranljivim materijama, jer se povećava telesna masa životinja. Iz tog razloga, neophodno je, da se u određenom periodu godine obavlja prihrana kako domaćih životinja na pašnjacima tako i divljih životinja u otvorenim i ograđenim lovištima, posebno u sušnim godinama. Pored toga nepristupačnost terena za prihranu domaćih i divljih životinja nameću potrebu za konstruisanjem automatske hranilice koja samostalno dohranjuje životinje tokom dana u tačno određenim vremenskim intervalima. Najčešće korišćena oprema za prihranu životinja su korita u koja se ručno povremeno dodaju žitarice i koncentrovana hrana. Takođe, postoje rešenja sa bunkerom iznad korita koji gravitaciono dodaju hranu kada se korito počne prazniti odnosno kada životinje počnu da jedu hranu.U intenzivnom tovu životinja, kliznim hranilicama se tačno određena poludnevna količina hrane sipa u korito. Zadatak radnika je da svako jutro i veče napuni hranilicu [14], [10], [12].

Sa hranilicama velikog kapaciteta koje se jednom mesečno pune rešava se problem radne snage, jer su konstruisani uređaji za hranjenje autonomni i ne zahtevaju stalni nadzor i angažovanje radnika. Prihrana bi trebala da se obavlja dva puta dnevno u tačno određeno vreme uz zvučni poziv životinjama. Dozirane količine koncentrovane hrane mogu da se povećavaju u jesen i smanjuju u proleće u zavisnosti od toga da li prinos biomase raste ili opada.

Izrada hranilica i uređaja za raspodelu koncentrovane hrane je jedno od najvažnijih pitanja u tehnologiji ishrane životinja.

Napori konstruktora i zootehničara usmereni su prvenstveno na određivanje dužine, oblika i materijala od kojih su napravljeni hranidbeni stolovi odnosno jasla [11].

Cilj rada je prikazati konstrukciju i utvrditi preciznost rada prototipa uređaja za prihranu koncentrovanom hranom domaćih životinja u slobodnom uzgoju na pašnjacima i divljih životinja u slobodnim i ograđenim lovištma.

MATERIJAL I METODE RADA

Eksploataciona istraživanja prototipa automatskog uređaja za prihranu životinja sprovedena su na porodičnom gazdinstvu (stračkom domaćinstvu) Trišović Rakine u selu Miločaju (Kraljevo). Uređaj je ispitivan pet dana u toku raspodele hrane u jutarnjem i večernjem obroku krava. Svakoga dana količina hrane je povećavana za 0,2 kg. Na automatskom uređaju za prihranu ima 8 hranidbenih mesta za životinje, na kojima je određena količina hrane koja je dozirana u jedinici vremena rada spirale uređaja. Nakon toga je na vagi vršeno merenje količine raspodeljene hrane na mestu za hranjenje. Merenja su vršena u tri ponavljanja. Na osnovu merenja izračunata je srednja vrednost raspodeljene količine hrane za svako hranidbeno mesto i utvrđena preciznost uređaja za prihranjivanje životinja.

REZULTATI ISTRAŽIVANJA I DISKUSIJA

Konstrukcija i princip rada hranilice

Automatski uređaj za prihranu domaćih i divljih životinja treba da reši problem svakodnevne prihrane i doziranja koncentrovane stočne hrane u slobodnoj, ekološkoj i organskoj proizvodnji domaćih životinja. Pored toga, može da se koristi za prihranu divljih životinja u otvorenim i zatvorenim lovištima u toku zime kada su visoke snežne padavine i veliki snegovi, kao i pri dugim letnjim sušama. Uređaj se sastoji od: kontejnera za smeštaj koncentrovane stočne hrane, spirale sa varijatorom i elektromotorom, dupleks korita za prihvat dozirane hrane, automatike, pojilica, aparat za zaštitu stoke od insekata, konstrukcije koja nosi i objedinjuje ove elemente. Napajanje električnom energijom može biti sa električne mreže, ako je ona u blizini, ili pomoću solarnih fotonaponskih panela.

Uređaj je instaliran na armiranoj betonskoj platformi za koje se pomoću fundamentalnih vijaka pričvršćuju stope. Na stubove teleskopskih stopa postavljene su pojilice sa svežom pijaćom vodom. Teleskopska stopala omogućuju da se uređaj za prihranu domaćih i divljih životinja može instalirati na kosim i neravnim terenima tamo gde nije neophodno postaviti betonsku ploču kao osnovu za montiranje uređaja.

Postoje dva reda pojedinačnih hranilica iznad kojih se nalazi kontejner u kome se lageruje koncentrovana hrana. Zapremina kontejnera za smeštaj koncentrovane hrane se razlikuje od tipa hrane, vrste životinja koje se prihranjuju i perioda vremena njegovog dopunjavanja. Iz ovih razloga njegova zapremina može biti od par desetina litara do par hiljada litara. Na dnu kontejnera nalazi se pužni transporter sa spiralom koji dobija pogon od elektomotora sa varijatorom.

Broj okretanja spirale transportera može da se podešava, a time i količina dozirane hrane u hranilici. Iznad svakog podesivog otvora hranilice nalazi se blenda koja sprečava da koncentrovana hrana gravitaciono ispada kada se spirala ne okreće.

Zavojni transporteri sa spiralom su ugrađeni u uređaj za prihranu, jer su pogodni za transport rasutog materijala, koncentrovane hrane na manja odstojanja [16], [15].

Korak zavojnice je izračunat po obrascu koje navode [13].

$$S = \pi \cdot D \cdot tg\alpha = j \cdot D \ [m] \tag{1}$$

gde je:

D – spoljni prečnik zavojnice u m;

α – ugao nagiba 14 - 18°;

j – 0,8 – 1,0;

Pogon zavojnice se izvodi preko reduktora.Vratila zavojnice i reduktora se međusobno vezuju spojnicom koja može da radi i prima lim odstupanjima pravaca ovih osa, dok se vratila elektromotora i reduktora vezuju elastičnom spojnicom.

Kapacitet zavojnog transportera se određuje na sledeći način:

$$Q = 3600 \cdot A \cdot \rho \cdot v \cdot \beta \ [t/h] \tag{2}$$

gde je:

A – površina poprečnog preseka sloja materijala u žlebu

$$A = \frac{(D^2 - d^2)\pi}{4}\psi \tag{3}$$

D – prečnik zavojnice, m;

d – prečnik osovine, m;

ψ – koeficijent punjenja žleba, 0,15 – 0,45;

β- koeficijent koji uzima u obzir nagib transportera;

pri uglovima nagiba od α=15 - 18° , može se uzeti $\beta \approx 0,02\alpha$;

v – brzina kretanja materijala

$$v = \frac{S\,n}{60} \tag{4}$$

S – korak zavojnice; n – broj obrtaja zavojnice.

Kombinacijom gornjih jednačina možese izraziti prečnik zavojnice. Snaga motora zavojnog transportera troši se na savlađivanje otpora koji nastaju pri procesu transporta. Ti otpori su uglavnom: otpori pri dizanju materijala, trenje materijala o žleb, trenje o zavojnicu, trenje u ležištima, otpor od mešanja i drobljenja materijala, otpor trenja u prenosnom mehanizmu. Snaga na vratilu zavojnice se računa kao:

$$N_{vz} = \frac{kQ}{367}(L\xi \pm H) \quad [kW] \tag{5}$$

gde je:

Q – kapacitet transportera u [t/h];

L – dužina horizontalne projekcije transportera u m;

ξ – koeficijent otpora kretanja materijala koji se može uzeti: za teške habajuće materijale (cement, gips, pesak ...) ξ=4, a za ugalj ξ=2,5;

H – visina dizanja materijala u m;

k – 1,15÷1,25 – stepen sigurnosti. Snaga motora za okretanje zavojnice se računa kao:

$$N_m = \frac{N_{vz}}{\eta}[kW] \tag{6}$$

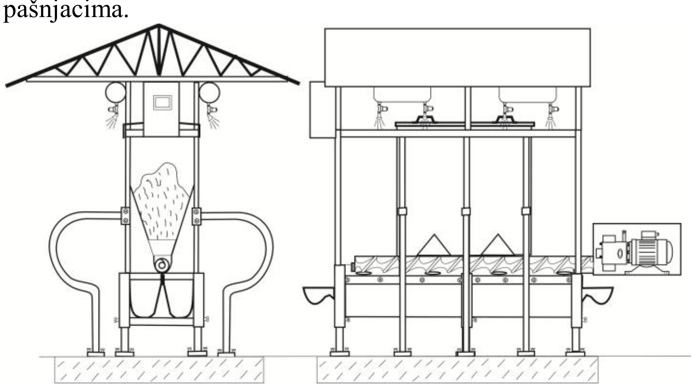
gde je: η – stepen korisnosti transportera (0,8-0,85)

U okviru automatike postoji vremenski tajmer koji ima usklađeno vreme sa lokalnim vremenom. To vreme se podešava na tač panelu. Drugi parametar koje se podešava je u koje vreme će se dozirati hrana. Treći parametar je koliko dugo će se dozirati hrana. Četvrti parametar je podešavanje vremena i dužine trajanja zvučnog pozivanja stoke da dođu do hranilice.

Neposredno pred punjenje korita sa koncentrovanom hranom uključi se zvučni alarm koji poziva krave ka hranilici i to dva puta dnevno u 7:00 h i 18:00 časova. Na ovaj način omogućeno je, da se potpuno samostalno, dohranjuju i napajaju domaće životinje u organskom, ekološkom i slobodnom uzgoju na livadskim površinama, kao i divlje životinje u otvorenim i zatvorenim lovištima.

Rezultati istraživanja i diskusija

Prototip automatskog uređaja za prihranu na pašnjacima predstavlja nov pristup u prihrani domaćih i divljih životinja. Ostvaruje prihranu životinja potpuno autonomo u pravilnim vremenskim razmacima. Važno je napomenuti da nadzor čoveka nije potreban čak u vremenskom trajanju od 60 dana. Neophodno je samo da se kontejner hranilice napuni koncentrovanom hranom što je dovoljno za navedeni vremenski period u zavisnosti od dnevnih potreba i broja krava. Eksperimentom je obuhvaćeno ukupno 10 izlučenih mlečnih krava Simentalske rase (Domaće šareno), koje su gajene za tov od maja do oktobra meseca 2019. godine. U toku eksperimenta krave su pod otvorenim nebom u prirodnim uslovima provodile na pašnjaku površine 10 ha. Prema autoru [14] za uspešan pašni tov goveda treba obezbediti i za svako glo površinu od 1 ha pašnjaka. Zbog nedovoljnih količina sveže kabaste hrane, farmer je svakodnevno ručno vršio prihranu krava koncentrovanom hranom, što je zahtevalo mnogo napornog fizičkog rada. Izgradnjom automatskog uređaja za prihranu krava fizički rad farmera je smanjen. Na Slici (1 i 2) prikazana je konstrukcija automatskog uređaja za prihranu domaćih i divljih životinja na pašnjacima.



Slika 1. Šematski prikaz Automatskog uređaja za prihranu domaćih i divljih životinja
Figure 1. Schematic diagram Automatic feeder for domestic and wildlife

Automatski uređaja za prihranu životinja je bio vrlo pouzdan u toku eksploatacije za vreme celog trajanja slobodnog tova krava i nije zabeležen nijedan kvar ni zastoj u radu. Takođe, uređaj je precizno vršio raspodelu hrane prema utvrđenim potrebama krava za prihranu u zavisnosti od raspoložive zelene mase travnjaka, vremena tova i telesne mase grla. U toku eksploatacije nije dolazilo do ispadanja i rasipanja hrane iz cilindričnog kućišta spiralnog transportera i korita hranilica. Pored toga, nije dolazilo do rasipanja hrane iz korita ni u toku konzumiranja hrane od strane krava.

Slika 2. Automatski uređaj za prihranu domaćih i divljih životinja
Figure 2. Automatic feeder for domestic and wildlife

Dozirana masa hrane je u funkciji rada spirale, tako da količina dozirane hrane u hranilici zavisi od vremena njenog rada (Tabela 1).

Rezultati istraživanja pokazuju da uređaj može da dozira hranu za goveda različitih kategorija i potreba za koncentrovanom hranom sa tačnošću od 5% odnosno 0,1 kg.

Tabela. 1. Količina dozirane hrane obroka (kg) u zavisnosti od vremena rada spirale $\Delta\tau(s)$
Table 1. Amount of dosed food of the meal (kg) depending on the working time of the coil $\Delta\tau$ (s)

Vreme rada uređaja *Device operating time*	Planirana količina hrane po hranidbenom mestu *Planned amount of food per feeding place*	Prosečna dozirana količina dozirane hrane po hranilici (Sa $\Delta\tau$=1 s) *Amount of dosed food per feeder (Sa $\Delta\tau$ = 1 s)*	
		Jutarnji obrok (kg) *Morning meal (kg)*	Večernji obrok (kg) *Evening meal (kg)*
1 dan	*2,0*	*2,0*	*2,1*
2 dan	*2,2*	*2,2*	*2,3*
3 dan	*2,4*	*2,3*	*2,5*
4 dan	*2,6*	*2,6*	*2,7*
5 dan	*2,8*	*2,8*	*2,9*

Rezultati ispitivanja pokazuju visoku pouzdanost i potpunu samostalnost u radu automatskog uređaja za prihranu domaćih i divljih životinja, i da se kao takav može primeniti u organskom i slobodnom uzgoju grla na pašnjacima.

ZAKLJUČAK

Na osnovu prikazanih rezultata može se zaključiti sledeće:

1. Automatski uređaj za prihranu domaćih i divljih životinja je pouzdano radio u eksploataciji od 5 meseci, bez zastoja i kvarova;
2. Doziranje koncentrovane hrane se može podešavati za sve kategorije domaćih životinja od najsitnijih (ovce, koze i svinje) do najkrupnijih (goveda i konji);
3. Preciznost doziranja se može povećati ako se rotiranje spirale smanji zahvaljujući smanjenju obrtanja osovine elektomotora. Ova regulacija se postiže sa varijatorom (reduktorom) ili frekfentnim regulatorom;
4. Pomoću uređaja hrana je precizno raspodeljena životinjama prema utvrđenim potrebama krava za prihranu u zavisnosti od količine i kvaliteta raspoložive travne mase i vremena tova.
5. U toku eksploatacije uređaja nije dolazilo do rasipanja hrane usled rasipanja na delovima uređaja niti od strane krava u toku konzumiranja.
6. Uređaj se može preporučiti i primeniti za prihranu domaćih i divljih životinja u slobodnom uzgoju na pašnjacima, jer je vrlo pouzdan i samostalan u radu.

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AUTOMATIC FEEDER FOR DOMESTIC AND WILD ANIMALS ON PASTURES

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Abstract: This paper presents a prototype of an automatic feeder for domestic and wild animals in organic farming. A simple, self-contained domestic and wild animal feeder was presented that has fully autonomous operation for up to 60 days. Electricity can be supplied from the mains and from photo voltaic cells max 100 W. The food dosing process of the container can be done one or more times a day. The amount of food to be added can be selected, ie the same amount of concentrated food is dosed each day, or the amount of dosed food is increased or decreased over time.

The results of testing the operation of the equipment in use were conducted on a single farm with several cows in organic farming. The monitoring of work in the period from May to October 2019 showed high reliability and complete independence in the operation of the automatic feeder for domestic and wild animals and that as such can be applied in organic breeding of domestic and wild animals.

Key words**:** *free animal breeding, nutrition, automatic feeder.*

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DEVELOPMENT OF A MOTORISED PLANTAIN CHIPPING MACHINE AND PERFORMANCE EVALUATION USING RESPONSE SURFACE METHODOLOGY

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Abstract: A motorised plantain chipping machine was developed. The machine is made up of a cutting device, a feeding mechanism, the support frame and an electric motor as a source of power. The cutting mechanism consists of the stainless steel blades, a connecting rod, a guide frame for the blades and pulleys. The blades are arranged perpendicular to the plantain tubers. During Performance Evaluation using Response Surface Methodology it was found that the chipping efficiency increased as the number of cutting blades are increased. Also the chipping efficiency increased with the speed of the machine but was not affected by the inclination angles of the blades. The linear effects of speed, the linear and quadratic effects of the number of blades significantly affected the chipping efficiency of the machine at 5% probability.

Key words*: plantain, electric, motor, chipping, machine, response, surface, methodology*

INTRODUCTION

Plantain is a basic food crop in developing countries, especially in Africa; it serves as one of the major foods for over 70 million people in the Continent. Plantain belongs to the family *Musa Spp.* and species of *Musa paradisiacal* and it originated from Southern Asia, [1].

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In some parts of Africa such as Nigeria and Ghana, plantains are dried and made into flour; plantain meal forms important food stuffs with the following constituents; water 10.62% protein 3.55%, fat 1.15%, carbohydrate 81.67% and ash 3.01% [1]. Plantain is a type of banana which is common in tropical regions. It is starchier and less sweet when compared to bananas. Plantains are usually served steamed, boiled or fried, although ripe plantains can be eaten raw. They are a rich source of antioxidants, vitamin B-6 and minerals, and their soluble fibred content may help ward off intestinal problems [2]. Plantain for local consumption plays an important role in food and income security and has the potential to contribute to national food security and reduce rural poverty [1]. Plantains provide the essential minerals that help the body to function efficiently. A 50gm of sliced or cooked plantain has 49 milligrams of magnesium and 716 milligrams of potassium, giving the body 15 percent of the recommended daily intake for each of these minerals [3]. The body needs magnesium for proper muscle contraction and nerve function, while potassium is a crucial component in the body fluids. A cup 50gm of plantain flour contains 5 to 10 percent of the iron need of the body. Iron helps to carry oxygen through the bloodstream which serves as a benefit to the muscles of the body. Although raw plantain is bitter and starchy, some people like them raw. They are more nutritious raw, with about 10 percent more magnesium, phosphorus and potassium. A cup of 50gms raw plantains has 27 milligrams of thiamine, a B-vitamin that helps the body's cells use carbohydrates as energy and helps ensure the proper functioning of the heart muscles and the nervous system [2]. Plantain processed into flour can be stored for up to a maximum of two years [1]. The ripe fruit is pureed, candied, and preserved in various forms when not eaten fresh. The extracts are used in the manufacture of catsup, vinegar, and wine. The unripe fruit can be powdered or chipped.

Slicing operation is achieved by cutting, which involves rotation of thin sharp blade with different configurations and speeds through the materials resulting in minimum rupture and deformation of the materials [4]. Reducing the size of food raw materials is an important operation to achieve a definite size range [5]. The traditional method of cutting plantains into chips has been observed to cause drudgeries, prone to finger injury, time consuming, produces irregular sized chips, and inevitably leads to low output by processors. The existing plantain chipping machines when tested were found to produce irregular sized, broken and discoloured chips which make the products unacceptable. The commonest methods of chipping plantain in our localities today include the use of knife, wooden platform plantain slicer, and metal cutter. These methods have a lot of deficiencies in terms of chipping time, efficiency, quality and safety. In view of this, there is need to improve on the existing plantain chipping machines by use of electric motor powered and highly efficient machine as obtained by this developed slicer. The purpose of the machine is to make chipping process less laborious especially for medium scale industries and for domestic purposes.

The objectives of this study therefore include; to design and fabricate a motorized small scale plantain chipper. To test the developed chipper for performance during operation and to analyse the experimental results obtained using Response Surface Methodology.

MATERIAL AND METHODS

Design Considerations

The following considerations were made during the development of the machine: Develop a machine that can produce uniform sized chips without discoloration.
Develop a machine that is smooth in operation with little noise.
To use locally available materials for its construction.
To develop a rigid and reliable machine when in operation.

Description of the Machine

The machine is made up of a cutting device, a feeding mechanism, the support frame and an electric motor as a source of power. The cutting mechanism consists of the stainless steel blades, a connecting rod, a guide frame for the blades and pulleys. The blades are arranged perpendicular to the plantain tubers. The feeding and the discharge mechanisms consist mainly of the Geneva drive mechanism meant to deliver intermittent motion to the conveyor, thereby causing the conveyor to move in a start-stop fashion. The drive shaft is supported by two ball bearings mounted on the base frame and which provide support for both radial and thrust loads. Plantains are fed into the hopper were they are discharged into the cutting chamber and are chipped by the cutting blades. The chips are discharged underneath the machine and are collected on a collector plate. Fig. 1 shows the orthographic drawing of the machine. Fig. 2 shows the orthographic model of the machine, while Fig. 3 shows the actual developed machine.

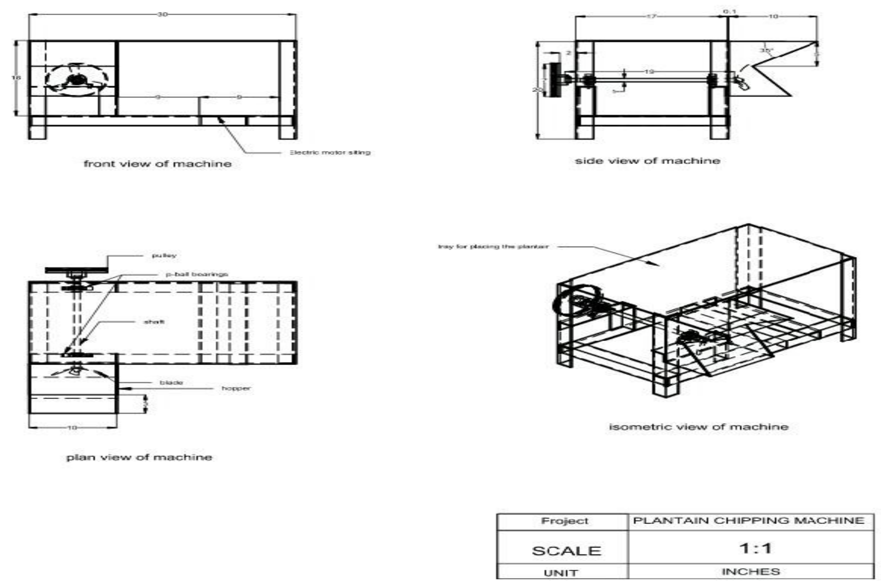

Figure 1. Orthographic View of the Plantain Chipping Machine

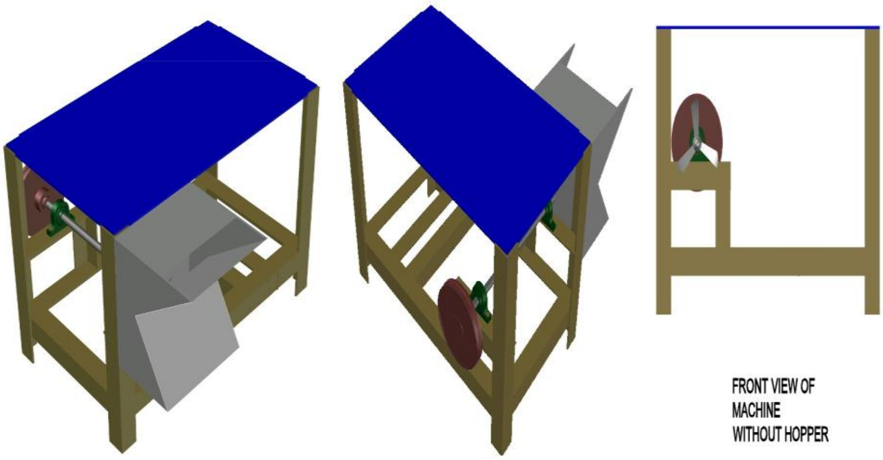

Figure 2. Orthographic Model of the Plantain Chipping Machine

Figure 3. The Developed Plantain Chipping Machine

Design Analysis

Volume of hopper: The hopper is triangular prism in shape and tilts at an angle at the base towards the cutting disc or flywheel. This triangular prism shape of the hopper is also maintained in the discharge chute. This concept is preferred because of the concept of repose angle and the coefficient of friction of plantain which must be maintained for it to freely fall into the flywheel. The eq. (1) shows the formula for calculating volume of hopper.

$V_{intake} = \frac{1}{2} a \times c \times h$ (1)

a = 17.78cm
c = 20cm
h = 22.86cm
Where
V_{intake} Is the volume at the intake chute
$\frac{1}{2} a \times c$ Is the base area of the triangular prism
h is the height of the prism
Therefore;

$$V_{intake} = \frac{1}{2}\ 17.78 \times 20 \times 22.86$$

V_{intake} = 8129.016cm^3
The hopper is half a prism, hence:
$V_{intake} = 0.5 \times 8129.016$ = 4064.5cm^3

Repose angle∅: This is the angle at which the plantain will slide down the slope of the hopper. It is shown in eq. (2).

Repose angle ∅ =$tan^{-1}\left({}^{y}/_{x}\right)$ (2)

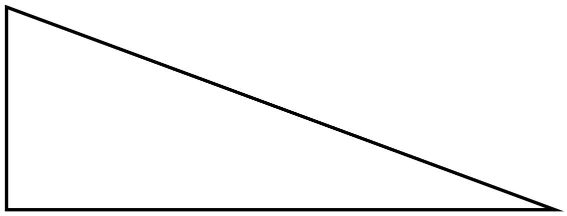

Figure 4. Relative Dimensions of the Hopper

Width of hopper = 22.86cm
$X = 17.78cm$
Y = ?
$H = 20.32$

Using Pythagoras theorem as shown in eq.(3),

$y^2 = H^2 - x^2$ (3)

$= y^2 = 20.32^2 - 17.78^2$

$y^2 = 96.77339 y = 9.8373772 \cong 10cm$

Therefore, Repose angle ∅ =$tan^{-1}\left({}^{10}/_{17.78}\right)$

∅ =tan^{-1} (10.363) $= 29.370 \simeq 30^0$

Hence the angle of repose is 30^0

Area of sliding surface (As): $As = width \times Height\ (H)$ (4)

$$= 22.86 \times 20.32, Area = 464.51cm^2$$

Assumed surface area of a finger of plantain from average measurement of width and length of various plantains of different species [6].

$Width = 5.08cm$

$Height\ (H) = 22.86cm$

$Areaofplantain\ (Ap) = 5.08 \times 22.86 = 116.1288cm^2$

$\boldsymbol{Area\ of\ Tray\ (At)}$;

$Length\ of\ trayLt = 76.2cm$

$Breath\ of\ trayBt = 43.18cm$

$$At = Lt \times Bt = 76.2 \times 43.18 \quad At = 3290.316cm^2$$

Diameter of the shaft

This involves the selection of the actual shaft diameter that can withstand the stresses encountered by the machine during safe operation. American standard shear stress of shaft $\tau = 56mPa$

Power = 1hp = 0.746 kW = 746 W

But power (P) as referenced in eq. (5) = $P = \frac{2\pi NT}{60}$ (5)

and T = $\frac{P\times 60}{2\pi N}$

Where T is the torque hence = $\frac{746\times 60}{2\pi\times 1440}$

T = $\frac{48760}{9048.96} = 4.9Nm$

Recall that $T = \tau \cdot \frac{\pi}{16} \times D^3$

T = torque

τ = shear stress

D = diameter of shaft

$D^3 = \frac{\tau.\pi}{16\times T}$ $= D^3 = \frac{56\times 3.142}{16 \times 4.95}$

D = $2.22cm$

Cutting blade

This is an integral part of the machine that slices the plantain. The size of chips is influenced by the cutting clearance and the speed of rotation of the blade. The clearance between the blade and the hopper $= 5.18cm$ therefore at the least and maximum speed, the obtainable sizes of plantain chips are at ranges of 2 and $5.5cm$.

Belt

The length of belt otherwise known as $effective\ belt\ length\ (Le)$ is a design parameter required for the selection of belt length to fit in sheave settings so as to avoid error that can lead to accidents.

Effective length of belt can be gotten using the formula outlined by [7] in eq. (6) as;

$$L_e = 2c + 1.57(D + d) + \left(D - {d}/{4c}\right)^2 \quad (6)$$

C = 41.91cm
D = 20.48cm
d = 16.51cm
Where;
L_e = the effective belt length
C = the design distance between the two pulleys (D and d)
D = the diameter of the driver pulley (cm)

$$L_e = 2(41.91) + 1.57(20.48 + 16.51) + \left(20.48 - {16.5}/{4(41.91)}\right)^2$$

$$L_e = 140.67cm$$

Capacity of the Machine

The machine is designed to cut 1 finger of plantain in 4seconds. That is, capacity of the machine = 1 plantain finger chipped in 4 seconds. A plantain finger weighs about 500gms. This translates to 7500gms per minute or 450kg/hr.

Electric Motor Specifications

A 1Hp electric motor was selected for the machine because of the estimated power requirements for the chipping operation.

RESULTS AND DISCUSSION

After the fabrication of the machine its operational performance was evaluated. A Faced Centred Response Surface Methodology using Central Composite Design was used to design the experiments. This method is useful because it uses very few experimental runs to describe how the test variables affect the response. It also helps to determine the inter-relationships among the test variables on the response and also helps to describe the combined effects of all the test variables on the response [8]. In the tests, three factors namely speed of the machine, the number of blades and the inclination angle of the chipping blades were investigated as they affected the chipping efficiency of the machine. The regression analysis was carried out with Minitab 16 software, while the response surface graphs were plotted with Matlab R2015a software.

The chipping efficiency of the machine was obtained using the method outlined in eq. (7) by [9] as;

$$Y = \frac{M - C}{M} \times 100 \quad (7)$$

Where, Y = chipping efficiency in percentage (%),
M = weight of plantains fed into the machine (gms)
C = weight of unchipped plantains (gms)

In the design the linear, interactive and quadratic effects of the factors (independent variables) as they affect the response (chipping efficiency) were studied [10]. Three levels of each of the factors were studied. They are listed as follows;

(i) Three different speeds of the machine, namely;
a. 325rpm (b) 650rpm (c) 975 rpm

(ii) Three different inclination angles of the blades, namely;
a. 300 (b) 450 (c) 600

(iii) Three different numbers of chipping blades, namely;
a. 3 blades (b) 6 blades (c) 9 blades

Table 1. Experimental Variables Used in the Design

Independent Variables	*Variable Levels*		
Speed of machine (rpm), X1	*975*	*650*	*325*
Blade inclination angles, X2	30^0	45^0	60^0
Number of chipping blades, X3	*3*	*6*	*9*
Code Designation	*1*	*0*	*-1*
Dependent Variable (Response)			
Chipping Efficiency (%) Y			

The coding using the design is as follows; 1 = highest factor, 0 = medium factor and 1 =lowest factor

Table 2. Experimental Results of Independent Variables and Response in Coded Terms

Runs	*X1*	*X2*	*X3*	*Y*
1	0	0	0	60
2	-1	0	0	47
3	-1	1	1	56
4	1	1	-1	58
5	1	-1	1	70
6	-1	-1	1	59
7	1	1	1	68
8	0	1	0	50
9	0	-1	0	46
10	0	0	0	50
11	-1	1	-1	47
12	0	0	0	49
13	0	0	0	48

14	*0*	*0*	*0*	*50*
15	*1*	*-1*	*-1*	*67*
16	*1*	*0*	*0*	*67*
17	*0*	*0*	*-1*	*57*
18	*-1*	*-1*	*-1*	*46*
19	*0*	*0*	*0*	*48*
20	*0*	*0*	*1*	*68*

Table 3. Response Surface Regression: Y versus X1, X2, X3

Term	*Coef.*	*SE Coef.*	*T*	*P*
Constant	*51.8455*	*1.458*	*35.570*	*0.000*
X1	*7.5000*	*1.341*	*5.594*	*0.000*
X2	*-0.9000*	*1.341*	*-0.671*	*0.517*
X3	*4.6000*	*1.341*	*3.431*	*0.006*
*X1*X1*	*3.6364*	*2.557*	*1.422*	*0.185*
*X2*X2*	*-5.3636*	*2.557*	*-2.098*	*0.062*
*X3*X3*	*9.1364*	*2.557*	*3.573*	*0.005*
*X1*X2*	*-1.1250*	*1.499*	*-0.750*	*0.470*
*X1*X3*	*-1.1250*	*1.499*	*-0.750*	*0.470*
*X2*X3*	*0.3750*	*1.499*	*0.250*	*0.808*
S = 4.23983				
R – Sq = 87.15%				

The regression equation is given as Y=51.85+7.50X1-0.90X2+4.60X3+3.64X1^2-5.36X2^2+9.14X3^2-1.13X1X2-1.13X1X3+0.38X2X3

Table 4. Analysis of Variance for Y

Source	***DF***	***Seq SS***	***Adj SS***	***Adj MS***	***F***	***P***
Regression	*9*	*1219.19*	*1219.19*	*135.465*	*7.54*	*0.002*
Linear	*3*	*782.20*	*782.20*	*260.733*	*14.50*	*0.001*
X1	*1*	*562.50*	*562.50*	*562.500*	*31.29*	*0.000*
X2	*1*	*8.10*	*8.10*	*8.100*	*0.45*	*0.517*
X3	*1*	*211.60*	*211.60*	*211.600*	*11.77*	*0.006*
Square	*3*	*415.61*	*415.61*	*138.538*	*7.71*	*0.006*
*X1*X1*	*1*	*174.05*	*36.36*	*36.364*	*2.02*	*0.185*
*X2*X2*	*1*	*12.01*	*79.11*	*79.114*	*4.40*	*0.062*

*X3*X3*	*1*	*229.55*	*229.55*	*229.551*	*12.77*	*0.005*
Interaction	*3*	*21.38*	*21.38*	*7.125*	*0.40*	*0.759*
*X1*X2*	*1*	*10.13*	*10.13*	*10.125*	*0.56*	*0.470*
*X1*X3*	*1*	*10.12*	*10.12*	*10.125*	*0.56*	*0.470*
*X2*X3*	*1*	*1.12*	*1.12*	*1.125*	*0.06*	*0.808*
Residual Error	*10*	*179.76*	*179.76*	*17.976*		
Lack-of-Fit	*5*	*74.93*	*74.93*	*14.986*	*0.71*	*0.639*
Pure Error	*5*	*104.83*	*104.83*	*20.967*		
Total	***19***	***1398.95***				

The experimental variables and coding are shown in Table 1, while the experimental results with the independent variables (in coded terms) are shown in Table 2. The estimated regression coefficients for chipping efficiency versus speed of the machine, blade inclination angle and the number of blades are shown in Table 3, while the analysis of variance associated with the regression are shown in Table 4. From Table 3, the linear effects of speed, the linear and quadratic effects of the number of blades significantly affected the chipping efficiency of the machine at 5% probability, ($P \leq 0.05$). These factors accounted for 87.15% of the variation in the chipping efficiency of the machine.

The analysis variance Table 4 also confirms the results. From the response surface graph in Fig. 5, the speed of the machine increased with the chipping efficiency, but decreased as the cutting blade angle is increased. From the response surface plot in Fig. 6, the chipping efficiency increased as the number of cutting blades are increased. Also, the chipping efficiency increased with the speed of the machine. From Fig. 7, the number of cutting blades increased with the chipping efficiency.

However, the chipping efficiency was not affected by the blades inclination angles.

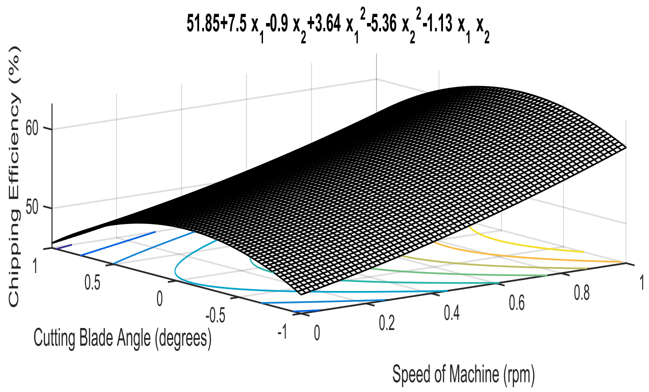

Figure 5. Response Surface Curve of the Effect of Cutting Blade Angle and Speed of Machine on the Chipping Efficiency of the Machine

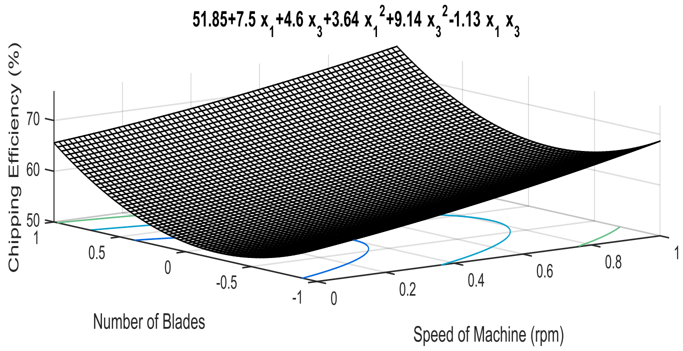

Figure 6. Response Surface Curve of the Effect of Number of Blades and Speed of Machine on the Chipping Efficiency of the Machine

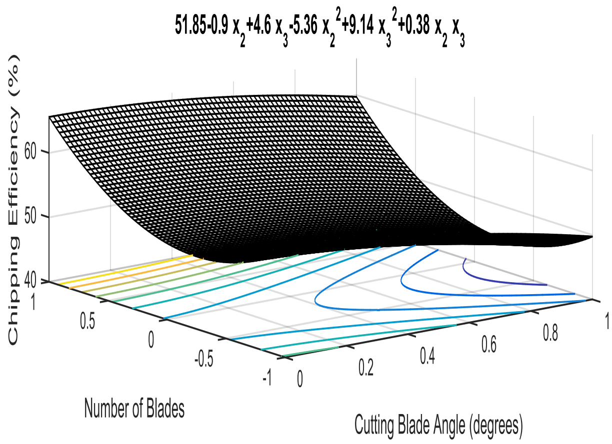

Figure 7. Response Surface Curve of the Effect of Number of Blades and Cutting Blade Angle on the Chipping Efficiency of the Machine

CONCLUSIONS

The machine performed satisfactorily during tests. It was observed that the machine produced uniform sized chips without discoloration and maintained good ergonomic characteristics in terms of noise and vibrations.

The chipping efficiency increased as the numbers of cutting blades are increased. Also the chipping efficiency increased with the speed of the machine but was not affected by the inclination angles of the blades.

The linear effects of speed, the linear and quadratic effects of the number of blades significantly affected the chipping efficiency of the machine at 5% probability.

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RAZVOJ STABILNE MAŠINE SA MOTOROM ZA SITNJENJE DRVNIH OSTATAKA I PROCENA UČINKA METODOM ODREĐENIH POVRŠINA

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Sažetak: Razvijena je stabilna mašina sa električnim motorom za usitnjavanje trupaca (stabala). Mašina ima: uređaj (mehanizam) za sečenje (lopatice-sečiva), mehanizam za privođenje delova drveta, ram i elektromotor kao izvor energije.
Mehanizam za sečenje sastoji se od specijalnih sečiva od nerđaju e g čelika, poluge, okvir za vođenje sečiva i remenice za pogon. Lopatice (sečiva) su postavljene normalno na pravac kretanja komada drveta (trupac).
Tokom procene performansi mašine sa primenom metodologije određene površine utvrđeno je da se efikasnost sečenja pove ava ako se pove ava broj sečiva. Takođe se efikasnost sitnjenja drveta pove avala sa porastom broja obrtaja rotora na kojem se nalaze sečiva, ali na efikasnost nisu uticali uglovi nagiba sečiva.
Linearni efekti brzine, linearni i kvadratni efekti broja sečiva značajno su uticali na efikasnost sečenja mašine za sitnjenje, sa verovatno o m od 5%.

Ključne reči: *trupac, električni, motor, usitnjavanje, mašina, određena površina, metodologija.*

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PHYSICAL PROPERTIES OF AFRICAN STAR APPLE FRUITS AND SEEDS

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Abstract: This research examines the physical properties of African star apple (*Chrysophyllum albidum*) fruits and seeds. The dimensions were measured with vernier calliper and the dimensional properties were computed using appropriate equations. The densities, porosity, angle of repose and coefficient of friction on three material surfaces were determined with standard methods from literature. The result of the study showed that the average major, intermediate and minor dimensions were 47.95 mm, 43.70 mm and 41.35 mm respectively for the fruits, and 26.05 mm, 15.12 mm and 6.07 mm respectively for the seeds. The volume, shape index and one thousand weight of fruits were obtained as 40.61 mm^3, 0.95 and 48.34 kg respectively whereas those of the seeds were obtained as 1.69 mm^3, 0.95 and 1.28 kg respectively. The true density, bulk density and porosity of the fruits were found to be 1710 kg/m^3, 1550 kg/m^3 and 52.63 percent respectively, while that of the seeds were found to be 950 kg/m^3, 570 kg/m^3 and 40.25 percent respectively. The sphericity obtained for the fruits and seeds were 0.94 and 0.55, respectively. Angle of repose was found to be 3.02^o and 13.50^o for the fruits and seeds, respectively. Coefficients of friction on plywood, mild steel and galvanized steel were 0.30, 0.24 and 0.20 respectively, for the fruits and 0.52, 0.46 and 0.39 respectively for the seeds. The empirical data from this study will aid researchers in the design and development of postharvest systems for the African star apple fruits and seeds postharvest operations.

Key words: *African star apple fruits and seeds, bulk and true densities, dimensions, postharvest.*

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INTRODUCTION

The African star apple *(Chrysophyllum albidum)* is a tree crop that belongs to the family of *Sapotaceae*. The fruits and seeds are valued greatly in many African nations where the tree flourishes. The fruit contains higher quantity of ascorbic acid (446 ± 2.5 mg/100 g dry matter) compared to guava (201.1 ± 0.7mg/100 g dry matter) or orange (28.89 mg/100 ml); and it also contains calcium, potassium, phosphorous, magnesium, tannins, flavonoids, terpenoids, and phytochemicals [1-4]. The nutritive value of the fruit makes it an excellent raw material for fruit jam, nectars, jelly and juice production [5-9]. According to [1], consumers of African star apple fruit have their blood sugar and cholesterol reduced. It was suggested that consumption of the fruit helps pregnant women for easy child delivery [10]. Some researchers [11] posit that the fruit is used to treat avitaminosis and dental decay in Benin republic. Each African star apple fruit has between 4-5 seeds [12]. The seed contains 10.71% oil, 18.34% crude protein, 6.48% fat and 4.63% crude fibre [13, 14]. The seed has potency in haemorrhoid and intestinal worm treatment [11].

Like many fruits, African star apple is a seasonal crop. The season spans between December and April [15]. The fruits are sold in markets and communities close to where they are grown. The fruit is yet to become an export commodity despite the potentials. The fruit suffers postharvest losses under ambient conditions [16, 17]. There is no standard storage and packaging systems for the fruits. This has further limited the commercialisation of the fruits. Therefore, there is need for the development of postharvest systems for the handling, processing and storage to guarantee availability of the fruits in and out of season. The design of such systems for postharvest operations of African star apple fruits and seed cannot be possible if their properties remain unknown. An attempt was made by [18] to investigate the properties of the seeds. However, their study failed to consider the properties of the fruits alongside.

The relevance of studying the physical properties of agricultural products cannot be overemphasized. As a result, many researchers have investigated the properties of various crops such as African breadfruit seed [19], yellow passion fruit seeds [20], kiwi fruits [21], *Cucurbita moschata* Duch. [22], date fruit varieties [23], groundnut pods and kernels [24], Canarium schweinfurthii Engl. fruits [25], Roselle calyxes [26], bottle gourd seeds [27], almond nut and kernel [28], wild mango fruit and nut [29], fluted pumpkin seed [30], African oil bean seed [31], Prosopis Africana seed [32], pistachio nuts and kernel [33], guan seed [34], among others. Apart from engineers, information on properties of biological materials is useful to scientists, processors and plant breeders [35].

Hence, the objective of this work was to determine the properties of the fruits and seeds of African star apple such as dimensions, densities, volume, porosity, angle of repose and coefficient of friction.

MATERIAL AND METHODS

Sample preparation

A bulk sample of freshly harvested African star apple fruits were obtained from Ngwa road market, Aba in Eastern Nigeria.

The fruits were manually cleaned and sorted to ensure that only good quality fruits are used for the experiment. Two-third of the bulk fruit sample were ripped open to extract the seeds. The moisture content of the fruits and seeds were determined using oven drying method at 105°C for 24 hours. One hundred samples of fruits and seeds were randomly selected from the bulk sample for the measurement of axial dimensions. The dimensions were measured at moisture contents of 61.89 percent and 37.62 percent respectively for the fruits and seeds.

Determination of the dimensions of the fruits and seeds

The three principal axes, major (a), intermediate (b) and minor (c) dimensions of each fruit and seed were measured using digital vernier calliper (Mitutoyo, Japan) with an accuracy of 0.01 mm. The geometric mean dimension (D_g), arithmetic mean dimension (D_a), sphericity (φ)and square mean dimension (D_s) were computed using Equations (1), (2), (3) and (4) thus [18, 32, 34]:

$$D_g = (abc)^{1/3} \tag{1}$$

$$D_a = \frac{(a+b+c)}{3} \tag{2}$$

$$\varphi = \frac{(abc)^{1/3}}{a} \tag{3}$$

$$D_s = \left(\frac{ab+bc+ac}{3}\right)^{1/2} \tag{4}$$

The shape index of the fruits and seeds was determined using the following Equation [36]:

$$Shape\ index = \frac{a}{\sqrt{bc}} \tag{5}$$

Determination of the gravimetric properties

One thousand weight of both the fruit and seed was determined using the method described by [37, 38] where 100 fruits and seeds were weighed separately with an electronic balance and multiplied by ten. The average mass of five replications was taken as the mean.

The bulk density (ρ_b) of the fruits and seeds was measured with the method used by [39]. The method involves weighing separately the fruits and seeds parked in containers of known volume. The sample was densely packed by gently tapping the container to allow the settling. Then the bulk density was computed as:

$$\rho_b = \frac{weight\ of\ material\ packed}{known\ volume} \tag{6}$$

The true densities (ρ_t) of the fruits and seeds were determined using water displacement method. A sample was measured and the weight (W_s) and number of samples (n_s) in each experiment carefully noted. The sample was poured into a measuring cylinder of known volume, and the volume of water displaced was recorded. The true density was then computed thus:

$$\rho_t = \frac{W_s}{V_s} \tag{7}$$

The individual weight and volume of samples were determined from the measurements taken for true density. The porosity was calculated using the relationship between bulk and true densities [35]:

$$p = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \tag{8}$$

Determination of the frictional properties

The frictional properties which consist of the angle of repose and coefficient of frictions were studied for the seeds and fruits using the following methods.

Angle of repose

This was determined using a topless and bottomless cylinder as reported by [32, 40, 41]. The cylinder was placed over a smooth circular plate and filled with the fruits to a reasonable level. Then the cylinder was raised slowly allowing the fruits to flow down and form a natural cone. The height of the cone (*H*) and the diameter (*D*) were measured and the angle of repose calculated using the following Equation:

$$\theta_r = tan^{-1}\left(\frac{2H}{D}\right) \tag{9}$$

Coefficient of friction

The static coefficient of friction was determined using an inclined plane [42]. The inclination of the test surface was gradually increased until the box just started to slide down and the angle of tilt (α) was read from the graduated scale attached to instrument. Three different material surfaces, namely, plywood, mild steel and galvanized steel were used to measure the friction coefficient of fruits and seeds on them. Five replications were taken for each test surface.

For each replication, the sample in the container was emptied and refilled with new sample. The static coefficient of friction (μ_s) was then calculated from Equation (10) given by [40]:

$$\mu_s = \tan \alpha \tag{10}$$

RESULTS AND DISCUSSION

Dimensional properties

The average values for the major, intermediate, minor, arithmetic mean, geometric mean and square mean dimensions of African star apple fruit are 47.95 mm, 43.70 mm, 41.35 mm, 42.82 mm, 42.80 mm, and 12.08 mm respectively, as shown in Table 1.

The arithmetic and geometric mean dimensions are higher than the minor dimension but lower than the major and intermediate dimensions (Table 1). This follows the same trend for bottle gourd seeds [27].

Table 1. Physical properties of African star apple fruit

Properties	*Minimum*	*Mean*	*Maximum*	*SD*
Major axis, mm	*40.83*	*47.95*	*58.80*	*4.19*
Intermediate axis, mm	*36.11*	*43.70*	*56.12*	*4.05*
Minor axis, mm	*37.86*	*41.35*	*46.31*	*2.73*
Arithmetic mean dimension, mm	*39.09*	*42.82*	*48.31*	*2.86*
Geometric mean dimension, mm	*39.06*	*42.80*	*48.23*	*2.86*
Square mean dimension, mm	*11.35*	*12.08*	*13.26*	*0.55*
Shape index, dimensionless	*0.92*	*0.95*	*0.96*	*0.01*
Sphericity, dimensionless	*0.92*	*0.94*	*0.95*	*0.01*
Unit volume, mm^3	*30.3*	*40.61*	*50.1*	*6.81*
Unit weight, g	*38.5*	*48.92*	*60.4*	*6.72*
One thousand weight, kg	*47.14*	*48.34*	*49.11*	*0.69*

SD is the standard deviation

The relationship between the dimension ratio a/b, a/c, a/D_g and a/D_a can be expressed as:

$$a = 1.10b = 1.16c = 1.12D_g = 1.12D_a$$

This indicates that the intermediate, minor, geometric mean and arithmetic mean dimensions have positive relation with the major axis.

The mean values of African star apple shape index and sphericity are 0.95 and 0.94 respectively.

The sphericity value falls within the range of 0.32 – 1.00 for most agricultural materials [35]. The value of the sphericity that is closer to 1.00 shows that the fruit has high tendency to roll than slide [29, 41].

Dimensions of the African star apple seed

The average values for the major, intermediate, minor, arithmetic mean, geometric mean and square mean dimensions of African star apple seeds were 26.05 mm, 15.12 mm, 6.07 mm, 15.63 mm, 14.91 mm, and 6.06 mm respectively, as shown in Table 2. The shape index and sphericity were obtained as 0.95 and 0.55, respectively. Unlike the fruit, the African star apple seed will not roll easily because of its relative low sphericity value of 0.55.

Table 2. Physical properties of African star apple seed

Properties	*Minimum*	*Mean*	*Maximum*	*SD*
Major axis, mm	*21.81*	*26.05*	*31.64*	*1.81*
Intermediate axis, mm	*12.55*	*15.12*	*17.78*	*1.09*
Minor axis, mm	*8.49*	*6.07*	*10.69*	*0.59*
Arithmetic mean dimension, mm	*17.49*	*15.63*	*18.83*	*0.93*
Geometric mean dimension, mm	*15.81*	*14.91*	*17.03*	*0.68*
Square mean dimension, mm	*6.50*	*6.06*	*6.84*	*0.23*
Shape index, dimensionless	*1.02*	*0.95*	*1.12*	*0.05*
Sphericity, dimensionless	*0.58*	*0.55*	*0.63*	*0.02*
Unit volume, mm^3	*1.85*	*1.69*	*1.99*	*0.09*
Unit weight, g	*1.33*	*0.70*	*1.70*	*0.21*
One thousand weight, kg	*1.30*	*1.28*	*1.32*	*11.35*

SD is the standard deviation

Gravimetric and frictional properties of the fruits and seeds

The average values of the bulk and true densities of African star apple fruits were found to be 1550 kg/m^3 and 1710 kg/m^3, respectively (Table 3). The bulk and true densities of the fruit are higher than that of the seeds average values found to be 570 kg/m^3 and 950 kg/m^3 respectively (Table 4). The densities are in the range obtained for the seeds at 8.49 percent moisture content dry basis [18]. The true density of the fruit is higher than that of Pistachio kernel (1082.73 – 1087.98 kg/m^3) and Pistachio nuts (1180.75 – 1210.50 kg/m^3) as reported by [33].

The bulk density of the seed is close to the values of Pistachio bulk density, 465.38-576.20 kg/m^3 [33] and higher than that of groundnut, 479.28 kg/m^3 [43].

The porosity of the fruit, which is dependent on the bulk and density densities, was higher than that of the seed. The average value of the fruit porosity was obtained as 52.63 percent (Table 3) whereas that of the seed is 40.25 percent (Table 4).

The porosities of both the fruit and the seed are within the range of porosity of karingda seed, 40.7 – 57.6 percent, reported by [42]. The porosity is important in designing drying, packaging and storage systems for the product. The angle of repose, which is the angle at which the product will stand when piled, was obtained as 3.02^o and 13.50^o respectively, for the fruit and the seed (Tables 3 and 4). These values are below the highest possible angle of repose of 45^o for most agricultural products [35].

The fruit's coefficient of friction was found to be 0.30, 0.24 and 0.20 on plywood, mild steel and galvanised steel surfaces, respectively (Table 3).

The coefficient of friction of the fruit on galvanized steel is similar to that of Garcinia kola seeds (0.20) on galvanized steel surface [41] and the value on plywood compares well with the value obtained for oilseed bean on glass (0.29) as reported by [44].

Table 3. Gravimetric and frictional properties of African star apple fruit

Properties	*Minimum*	*Mean*	*Maximum*	*SD*
Bulk density, kg/m^3	*1200*	*1550*	*1800*	*0.20*
True density, kg/m^3	*1380*	*1710*	*1940*	*0.18*
Angle of repose, degree	*2.87*	*3.02*	*3.20*	*0.12*
Porosity, %	*51.04*	*52.63*	*53.12*	*0.61*
Coefficient of friction on:				
Plywood	*0.28*	*0.30*	*0.31*	*0.004*
Mild steel	*0.23*	*0.24*	*0.26*	*0.007*
Galvanized steel	*0.19*	*0.20*	*0.22*	*0.008*

SD = standard deviation

Table 4. Gravimetric and frictional properties of African star apple seed

Properties	*Minimum*	*Mean*	*Maximum*	*SD*
Unit weight, g	*1.33*	*0.70*	*1.70*	*0.21*
One thousand weight, kg	*1.30*	*1.28*	*1.32*	*11.35*
Bulk density, kg/m^3	*560*	*570*	*590*	*0.01*
True density, kg/m^3	*970*	*950*	*990*	*0.01*
Angle of repose, degree	*15.15*	*13.50*	*17.10*	*1.02*
Porosity, %	*42.71*	*40.25*	*44.83*	*0.43*
Coefficient of friction on:				
Plywood	*0.52*	*0.50*	*0.54*	*0.02*
Mild steel	*0.46*	*0.44*	*0.48*	*0.01*
Galvanized steel	*0.39*	*0.34*	*0.42*	*0.03*

SD = Standard deviation

The coefficient of friction of the African star apple seed was found to be 0.50, 0.44 and 0.34 on plywood, mild steel and galvanised steel surfaces, respectively (Table 4). It was observed that these values are higher than that of the fruit on the same material surfaces. These data are valuable for the design of hoppers, conveying systems, and storage systems for the product.

CONCLUSIONS

The following conclusions were drawn from the investigation on the physical properties of African star apple fruits at moisture content of 61.89 percent (wet basis) and African star apple seeds at moisture content of 37.62 percent (wet basis). The average characteristic dimensions - major, intermediate and minor axes - of the fruit were 47.95 mm, 43.70 mm and 41.35 mm, respectively, whereas those of the seed were 26.05 mm, 15.12 mm and 6.07 mm, respectively. The bulk and true densities were found to be 1550 kg/m^3 and 1710 kg/m^3 for the fruits, and 570 kg/m^3 and 950 kg/m^3 for the seeds, respectively. The porosity was found to be 52.63 percent for the fruit and 40.25 percent for the seed. Angle of repose was obtained as 3.02^o for the fruit and 13.50^o for the seed. These empirical data for the various properties of African star apple fruit and seed will be useful in designing postharvest systems that will add value to the African star apple fruits and seeds.

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FIZIČKE OSOBINE PLODA I SEMENA JABUKE AFRIČKA ZVEZDA

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Sažetak: Ovo istraživanje prikazuje fizičke osobine plodova i semena jabuke Afrička zvezda (*Chrisophillum albidum*). Dimenzije su merene preciznim pomičnim merilom (nonijus-mikrometar). Karakteristične dimenzije izračunate pomo u odgovaraju ih relacija i jednačina.

Zapremina, poroznost, ugao nagiba i koeficijent trenja po podlozi za tri površine različitih materijala utvrđeni su standardnim metodama iz literature. Rezultat studije je pokazao da su prosečne velike, srednje i male dimenzije jabuke bile: 47,95 mm, 43,70 mm i 41,35 mm za plodove, odnosno 26,05 mm, 15,12 mm i 6,07 mm za seme jabuke.
Gustina, indeks oblika i težina hiljadu plodova, dobijeni su kao 40,61 mm^3, 0,95 i 48,34 kg, dok su semena dobijena kao 1,69 mm^3, 0,95 i 1,28 kg, retrospektivno. Utvrđeno je da su stvarna gustina, zapreminska težina i poroznost plodova 1710 kg/m^3, 1550 kg/m^3, odnosno 52,63 %, dok je određeno da je gustina semena 950 kg/m^3, 570 kg/m^3 i 40,25 % retrospektivno.
Dobijena sferičnost plodova i semena jabuke iznosila je 0,94, odnosno 0,55. Utvrđeno da je ugao mirovanja (nema kotrljanja) za plodove 3,02°, odnosno za seme 13,50°. Koeficijenti trenja po šper ploči, mekanom čeliku i pocinkovanom čeliku su vrednosti 0,30; 0,24, i 0,20 za plodove, odnosno 0,52; 0,46 i 0,39 za semena jabuke.
Empirijski podaci iz ove studije pomo i e istraživačima u dizajnu i razvoju sistema čuvanja za plodove i semena jabuke Afrička zvezda (*Chrisophillum albidum*) posle berbe.

Ključne reči: *Plodovi i semena jabuke Afrička zvezda, zapremina i stvarna gustina, dimenzije, naknadna berba.*

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CONSTRUCTION, OPERATION AND MEASURING PROCESS OF TEST REACTOR FOR BIOGAS PRODUCTION

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Abstract: The purpose of the research is to build an experimental reactor to study and optimize the production of biogas and its composition from energy crops and other materials of organic origin. An experimental reactor in a biogas plant was constructed for the anaerobic digestion of various substrates. With the experimental reactor, anaerobic digestion can be performed with the basic substrate of pig manure and in different compositions of the substrate. The substrate can be assembled in various combinations of energy crops. The method of construction of the experimental reactor was based on the standard method DIN 38 414, also with the mentioned method we produce biogas under normal conditions from various substrates. The process also determines the quality of biogas or methane content. The built biogas reactor is a reduced version of the economic reactor and serves to optimize the production of biogas in economic conditions.

Key words*: test reactor, anaerobic fermentation, biogas*

INTRODUCTION

The use of renewable energy sources is becoming increasingly important, as we are increasingly aware of their limitations (especially the limitations of fossil fuels) and their impact on climate change.

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The research work was performed at the biogas plant Ekoteh (Panvita d.d.) as part of the doctoral dissertations of the candidate Matjaž Ošlaj.

In addition to replacing non-renewable sources with renewable ones, efficient use of energy and reduction of its consumption are also important for achieving sustainability and security of energy supply and for reducing greenhouse gas emissions. To achieve these goals, a number of activities are taking place at global, European and national levels. The advantage of using renewable energy sources is reflected in the positive impact on the climate, stability in energy supply and long-term economic benefits. The European Commission estimates that achieving the targets set in the climate energy package by 2020 will mean reducing CO_2 emissions by 600 to 900 million tones per year, reducing fossil fuel consumption by 200 to 300 million tonnes per year, reducing the EU's dependence on imported fossil fuels thereby increasing the stability of energy supply in the EU and greater incentives for the development of high-tech industries with new economic opportunities and jobs [1].

Many technologies are known for the direct use and processing of biomass into fuels. They are roughly divided into three groups: incineration, thermal chemical conversion, biological conversion [2].

Natural processes performed by bacteria, yeasts or enzymes in different organic substances under different temperature and oxidation conditions during the fermentation and composting process. Fuels obtained from biomass with the described technologies can also be classified into three groups (SOLID BIOMASS: incineration of wood biomass, waste from agricultural plants and energy crops and algae, LIQUID FUELS FROM BIOMASS: by fermentation into bioethanol, by pyrolysis into biomethanol and from seeds into biodiesel and BIOMASS GASES: by pyrolysis into production of gas and by anaerobic fermentation into biogas [2].

Biogas is a mixture of gases produced during anaerobic fermentation in a device, called a digester or reactor or. fermenter. Anaerobic fermentation is a biological process and is based on methanogenesis. In it, bacteria decompose organic material, and the decomposition product is mainly methane and carbon dioxide. It is generated in the processes of separate treatment of organic waste from agriculture, plant waste and sewage from livestock farming and from the use of purpose-grown biomass for energy production [3]. For the purpose of verifying the biogas potential from various materials, we built a digester and developed appropriate procedures according to which biogas production takes place in economic conditions. The obtained results are useful for biogas production for economic purposes.

MATERIAL AND METHODS

Near the existing biogas plants, we have set up a test reactor, which will be used to optimize the operation of economical biogas plants and to test new interested substrates for biogas production. The volume of the test reactor is 2500 liters, of which 2000 liters is the working volume and 500 liters is used for gas storage. The test reactor is a scaled-down version of the commercial reactor, as it can test the same treated substrate as in commercial reactors.

With the test reactor, we obtain more tangible results for a particular substrate compared to the results of various literatures, which mostly cover average results. The obtained results are used directly in economic devices and thus optimize the operation of economic devices and at the same time analyze the actual operation of the test device.

In addition to the test reactor, a 150-liter storage tank was provided for the purposes of homogenizing of certain substrates, sampling and storage of certain substrates.

The construction of a test reactor for the production of biogas from energy crops and other waste materials of organic origin was performed according to the German standard DIN 38 414, part 8 [4]. The standard is useful for determining the course of anaerobic fermentation of various organic substrates, the time course of gas development, the composition of gases as well as the composition of energy plants before and after the fermentation experiment.

At the beginning of the experiment, dry residue (according to DIN 38 414, part 2), organic dry matter (according to DIN 38 414, part 3) and pH value (according to DIN 38 414, part 5) were determined from the experimental substrates investigated. Then dry matter is determinate to the mixture of inoculum (base substrate) and co-substrate (according to DIN 38 414, part 4), organic dry matter and pH value (according to DIN 38 414, part 5), which must be within the basic range (pH is from 7 to 8). Inoculum is manure from a biogas plant, which serves as inoculum in the process of anaerobic fermentation. Large differences in its composition were observed in several samples of inoculum. Differences in the composition of the manure occur due to different categories (weight) of pigs and the composition of the feed mixtures during the feeding of pigs. According to the deviations in chemical composition, we decided to use one sample of inoculum for credibility in data processing. The inoculum was stored in the pool, where we had the option of storing a sufficient amount of it. To maintain the activity of microorganisms (bacteria) in the inoculum, a small amount (1 kg) of silage was added for a certain period of time (5 days).

Figure 1 shows a sketch of a test reactor filled with inoculum from a biogas plant. The reactor was set to a mesophilic heat range of 37.5 ° C with a tolerance of ± 1.5 ° C. Mixing was adjusted with a stirrer in the reactor (Figure 1) as in commercial plants.

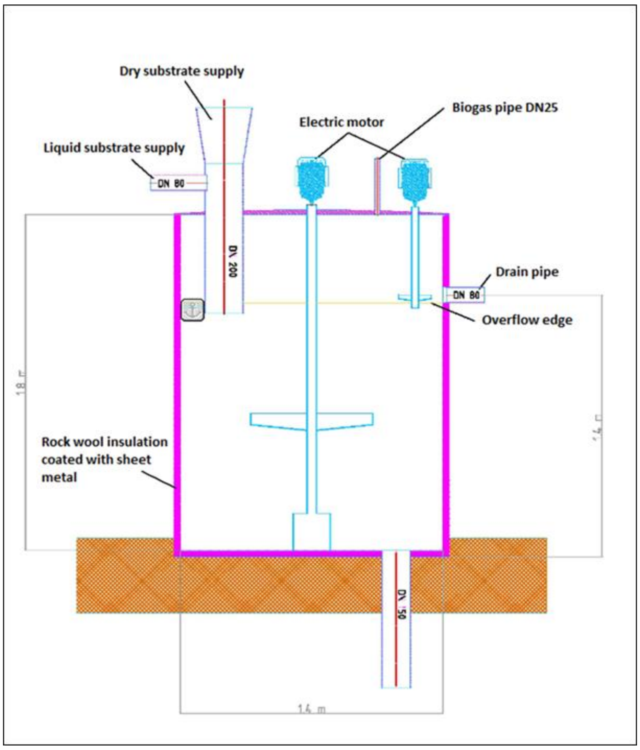

Figure 1. Test reactor

The produced biogas was expressed in norms of liters per unit of substrate (Nl/kg oDM) or in norms of cubic meters per ton of organic dry matter (Nm^3/toDM). The amount of biogas was recalculated according to normal conditions, i.e. To = 273 K and Po = 1013 mb [4].

The normal volume is the volume of gas produced from the various substrates. To evaluate the data, it is first necessary to perform the calculation of the normal volume in individual time periods of the developed biogas, with the equation:

$$Vo = V \cdot \frac{(Pl - Pw) \cdot To}{Po \cdot T} \tag{1}$$

where:

Vo – standard (normal) volume of biogas in ml;
V – measured volume of biogas in ml;
Pl – air pressure at the time of measuring in mbar;
Pw – water vapor pressure as a function of room temperature in mbar;
To – norm temperature To = 273 K;
Po – norm pressure Po = 1013 mbar;
T – temperature of biogas or surrounding space in K.

The proportion of fission gas production is then calculated with the equation:

$$V_{is} = \frac{\sum V_{is} \cdot m_{is}}{m_M} \tag{2}$$

where:

V_{is} – the volume of gas developed from the inoculum (inoculum is largely fermented sludge that is kept biologically active by the regular addition of small amounts of raw sludge), in ml; .
ΣV_{is} –the sum of the volume of gas in the experiment with inoculum in ml;
m_{is} – mass of inoculum used for mixtures in kg;
m_M – mass of inoculum used in the control experiment in kg.

The specific production of biogas or inoculum is calculated gradually from reading to reading according to the equation:

$$Vs = \frac{\sum Vn \cdot 10^4}{m \cdot Wt \cdot Wv}, \tag{3}$$

where:

Vs – specific biogas production in the norm of liters of biogas per kilogram of organic dry matter (Nl/kg oDM);
ΣV_n – net volume of gas produced from inoculum during the observation time in ml;
m – the mass of the weighed sample of inoculum (inoculum of this standard is raw sludge) in kg;
W_t – the dry residue of the test sample of the reference sludge (inoculum) in %;
W_v – the loss of dry mass combustion of the inoculum in the experiment in%.

Based on the estimated yield of fresh mass of the energy crop, we calculate the yield of dry matter and organic dry matter in kg/ha, taking into account the results of chemical analysis for dry matter and organic dry matter according to the equation:

$$PSS = \frac{SM \cdot SS}{100} \tag{4}$$

where:

PSS – dry matter yield in kg/ha;
SM – fresh mass yield in kg/ha;
SS – dry matter of the substrate in %.

The yield of organic dry matter of an individual energy plant was calculated according to the equation:

$$PoSS = \frac{PSS \cdot Wv}{100} \tag{5}$$

where:

PoSS – organic dry matter yield in kg/ha;
PSS – dry matter yield in kg/ha;
Wv – dry annealing losses in%.

Then we calculate the biogas yield (Nm^3/ha) based on the results of measurements of the amount and composition of produced biogas by individual energy plants according to the equation:

$$PB = \frac{PoSS \cdot B}{1000} \tag{6}$$

where:

PB – biogas yield in Nm^3/ha;
PoSS – organic dry matter yield in kg/ha;
B – biogas yield in Nl/kg oDM.

The yield of biomethane (N1/kg oDM) is calculated by multiplying the calculation of the specific production of biogas or inoculum (equation 3) by the amount of methane produced.

$$BM = \frac{Vs \cdot V}{100} \tag{7}$$

where:
BM – biogas yield in Nl/kg oDM;
Vs – specific biogas production in norms of liters of biogas per kilogram of organic dry matter (Nl/kg oDM);
V – methane content in %.

The yield of biomethane (Nm^3/ha) for an individual energy plant is calculated by the equation:

$$PBM = \frac{PoSS \cdot PM}{1000} \tag{8}$$

where:
PBM – biomethane yield in Nm^3/ha;
PoSS – organic dry matter yield in kg/ha;
PM – biomethane yield in Nl/kg oDM.

RESULTS AND DISCUSSION

Table 1 shows and describes the components of the experimental reactor. The amount of biogas produced was measured using a biogas flow meter. We also had to determine the maximum reactor load. For this we used the corn silage that we had the most at our disposal, and we know a lot about it from the literature. The load of the test reactor for the anaerobic digestion process was performed with 54 liters of slurry (base substrate) and 20 kg of silage (substrate). Using a pump with an electric motor (Figure 3c), we pumped the slurry into the test reactor.

Table 1. Components of the experimental reactor

Components	*Component properties*
Stirrer	*Horizontally at two heights, it is powered by a 500 W electric motor (Figure 2).*
Heater (heating pipes)	*It is installed inside on the walls of the reactor, it is heated by hot water from the heat exchanger (Figure 2).*
Additional stirrer at the outlet	*Horizontal mixer, height-adjustable in overflow edge, which prevents clogging at the outlet. It is powered by a 350 W motor (Figure 3b).*
Slurry pump	*An electric motor pump with which we pump manure into the reactor. Taking into account the losses in the pipeline, it pumps 2 liters of slurry into the reactor per minute (Figure 3c).*
Hopper for dry substrates	*Funnel-shaped opening into which dry substrates are poured at certain intervals (Figure 2).*
Biogas flow meter	*A mechanical meter that records the flow of biogas based on blade turns driven in our case by biogas (Figure 3a).*
Analyzer of biogas quality	*Portable biogas analyzer, with which we analyze the quality of biogas at certain intervals or as needed. We can measure the values of CH_4, CO_2, O_2 in percent and the value of H_2S in ppm (Figure 4d).*
Computer control box	*All devices on the reactor, except the biogas quality analyzer, are controlled by a computer via a control box (Figure 4).*
Other equipment	*Laboratory with all necessary equipment and other equipment for storage and handling of substrates.*
Sampling points	*They are at the six outlets of the ball valve reactor, where samples can be taken for analysis at different depths. Of these six discharges, two are 80 mm in diameter (Figure 2).*
Window	*A place with a glass door, through which we can observe what is happening in the reactor from the top.*
Stirrer outflow	*Stirrer for draining fermented manure.*

Figure 2 shows an experimental reactor designed for the purpose of biogas production from various substrates.

Figure 2. Experimental reactor

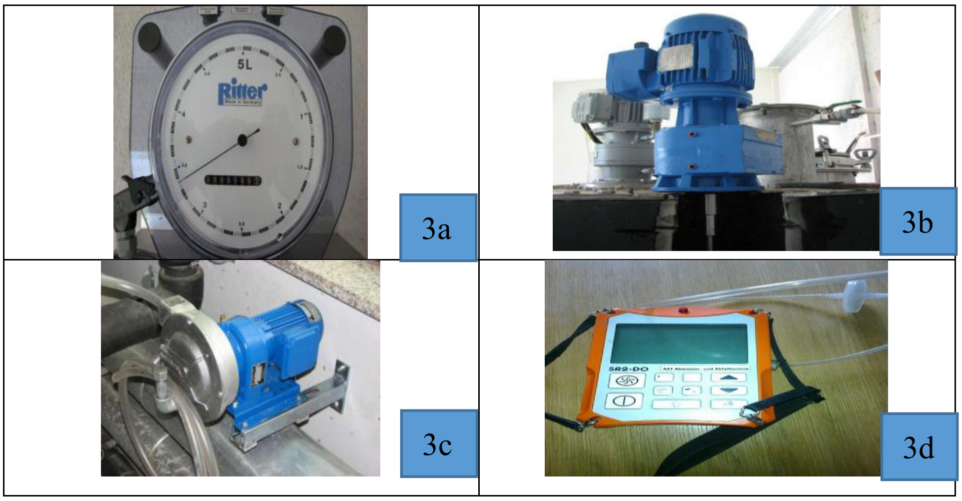

Figure 3. Different components of experimental reactor

Each sample tested contained the same amount of slurry (54 l of basic substrate) and silage (20 kg of substrate) daily. The amount of biogas produced was monitored continuously and recorded in a computer program every 12 seconds (Figure 4). Biogas quality was measured three times a week with a portable SR2 – DO analyzer (Figure 3d). We measured the values of CO_2, O_2, CH_4 in percent and the value of H_2S in ppm.

Reactor control (Figure 4) is automated through a control system that includes regulation, measurement and monitoring of biogas yield. The software is used to view and set the time control of the mixer, slurry pump, biogas flow meter, heater and biogas yield monitoring.

For each sample tested, we also performed titration to determine volatile fatty acids (VFA), according to the AAT procedure (AAT Biogas Technology 2007). The chemical titration process was performed using laboratory instruments such as: titration burette (for stepwise dosing, 0.02 ml each), pipette, magnetic stirrer, pH meter with thermometer, 250 ml beaker and blower. Samples were titrated with 0.05 M sulfuric (VI) acid, and a sample for titration was first prepared before titration. To this was added 120 mL of distilled water in a 5 mL sample. The sample beaker was placed on a magnetic stirrer, the temperature and initial pH of the sample were measured, and titration was started. This data was finally entered into a table in Excel and the value of volatile fatty acids (VFA) was calculated.

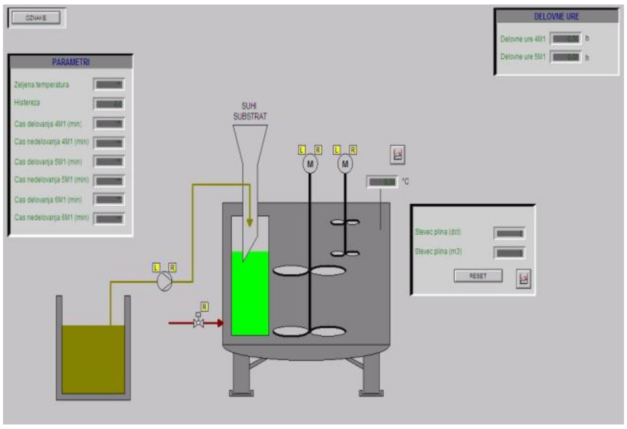

Figure 4: Software of Experimental Reactor

Anaerobic digestion is carried out with the basic substrate of pig manure and in different compositions of the substrate. For co-substrates, we used maize (main crop), maize (stubble crop), triticale (main crop), sorghum (main crop), a mixture of plants for biomass production (main crop) and maize as grain (grain at the waxy maturity stage). The substrates can be composed in various combinations of plant species in anticipation of high biogas yield. The test reactor can be used for biogas testing of other different organic waste materials (waste, water). Some results measuring biogas with experimental digester from various energy crops can be seen in different literature [5-6].

CONCLUSIONS

The production of biogas with anaerobic fermentation is one of the technologies that can contribute towards energy production, sustainable waste management and the reduction of greenhouse gas emissions. In order to optimize the anaerobic fermentation process of new substrates for biogas production, we build an experimental reactor and developed method for producing biogas from various energy crops and other organic waste materials. The built biogas reactor is a smaller version of the economic reactor and it works in a mesophilic temperature range as economical biogas plant.

The main purpose of the pilot reactor is to test the biogas potential of new economically interesting substrates, optimize the biogas production process and eliminate possible problems during production before using the new substrate in a commercial biogas plant.

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PROCES IZGRADNJE, RADA I MERENJA TEST REAKTORA ZA PROIZVODNJU BIOGASA

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Sažetak: Svrha istraživanja je izgradnja eksperimentalnog reaktora za proučavanje i optimizaciju proizvodnje biogasa i njegovog sastava iz energetskih useva i drugih materijala organskog porekla. Izveden je eksperimentalni reaktor u postrojenju za biogas za anaerobnu digestiju različitih supstrata. Sa eksperimentalnim reaktorom, anaerobna digestija se može izvršiti sa osnovnom podlogom stajnjaka od svinja i različitim sastavima substrata. Podloga (substrat) može se sastaviti od različitih kombinacija energetskih useva. Način izrade eksperimentalnog reaktora zasnovan je na metodi standarda DIN 38 414. Takođe pomenutom metodom mi proizvodimo biogas u normalnim uslovima iz različitih podloga. Proces takođe određuje kvalitet sadržaja biogasa ili metana. Izgrađeni reaktor za biogas je redukovana verzija ekonomskog reaktora i služi za optimizaciju proizvodnje biogasa u ekonomskim uslovima.

Ključne reči: *test reaktor, anaerobna fermentacija, biogas*

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COMPUTATIONAL MODEL OF THE FUEL CONSUMPTION AND EXHAUST TEMPERATURE OF A HEAVY DUTY DIESEL ENGINE USING MATLAB/SIMULINK

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Abstract. A model of a diesel engine and its electronic control system was developed to investigate the engine behaviour in a vehicle simulation environment. The modelled quantities were brake torque, fuel consumption and exhaust gas temperature and were based on engine speed and pedal position. In order to describe these outputs the inlet air flow and boost pressure were also modelled and used as inner variables. The model was intended to be implemented on board a vehicle in a control unit which had limited computational performance. To keep the model as computationally efficient as possible the model basically consists of look-up tables and polynomials. First order systems were used to describe the dynamics of air flow and exhaust temperature. The outputs enable gear shift optimization over three variables, torque for vehicle acceleration, fuel consumption for efficiency and exhaust temperature to maintain high efficiency in the exhaust after treatment system. The engine model captures the low frequent dynamics of the modelled quantities in the closed loop of the engine and its electronic control system. The model only consists of three states, one for the pressure build up in the intake manifold and two states for modelling the exhaust temperature. The model was compared to measured data from an engine test cell (as got in INNOSON NIG. LTD.) and the mean absolute relative error were lower than 6.8%, 7.8% and 5.8% for brake torque, fuel consumption and exhaust gas temperature respectively. These results were considered good given the simplicity of the model.

Keywords: *Computational models, brake torque, fuel consumption, exhaust gas temperature, heavy duty diesel engine*

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INTRODUCTION

Concerning the complex structure of the modern heavy duty diesel engine, the main issue in the field is how to maintain the best levels of efficiency, reliability and lifecycle cost. Diagnosis during improper operation is difficult to perform. Furthermore, testing engine control units (ECUs) directly in real engine laboratories is too expensive. Some operations and environmental limitations cannot be addressed satisfactorily in the engine laboratory, but these limitations can be overcome by diesel engine modelling simulations, which can not only estimate some hard to measure engine features, but also avoid higher experiment and time costs. In the modern process of engine control system development, the verification & validation mode based on computer aided control system design is becoming more and more important (Skogtjärn, 2012).

The model-based development mode also serves to illustrate the fact that control-oriented engine models are more essential (Pérez *et al.*, 2016).

A lot of engine models have been developed for different applications, and the mean value model (MVM) is widely used in the control field because of its capability of observing engine states and capturing transient responses (Skogtjärn, 2012). The mean value engine model has traditionally suffered from several essential downsides which were suggested to improve the response speed of engine models (Sun *et al.*, 2011).

Based on the basic model, some literature has combined MVM with neural networks to attain both real-time performance and high precision. Since MVM is a time-domination model, ignoring the combustion process, some literature implement crank angle-based models directly into MVM to predict the engine performance. There is also a lot of work implementing emission models in the form of look-up tables, algebraic polynomial expressions or neural network models into MVM to predict engine emissions (Pérez *et al.*, 2016).

The injection system supplying fuel to a diesel engine is considered as a controlling signal in a MVM model. The injection model should have more details in a HIL testing system. In reference, a distributed model for the common rail injection system based on using basic fluid flow equations was presented. A fuel injection system driving fuel from the tank to the combustion chamber can be found in, and this model can be used for control applications (Pérez *et al.*, 2016).

The cooling system maintains the operating temperature of the engine while the coolant temperature is important to the engine and control system. Cooling systems are widely investigated by modelling and experimental tests since engine thermal management is an important way to reduce engine fuel consumption and to increase efficiency. Some cooling systems use mechanical pumps which are modelled by dynamic thermal modelling or hydraulic circuits. Another cooling system equipped with an electric pump can also be found in Flärdh and Gustafson (2004). The lubrication system provides a protective layer to prevent metal to metal contact, especially between piston rings and cylinder walls (Sun *et al.*, 2011).

For heavy duty truck development reducing fuel consumption is an important task as fuel cost is a major expense for the hauliers. Today AMT's (Automated Mechanical Transmission) are widely used in heavy trucks. The AMT developed at Volvo Truck Technology (I-Shift) has twelve forward gears. When the truck is lightly loaded or unloaded single gear steps would result in very short times between shifts. This results in insufficient acceleration and poor comfort.

Other important factors to consider when choosing gear are road inclination and the engine performance. This requires a sophisticated gear shift strategy, i.e. deciding how many gear steps to shift and when to shift.

Simulating the vehicles behaviour during shifts to different gears gives a good basis to evaluate which gear to choose and when to shift. A simulation environment of the translatory motion of the vehicle provides the possibility to predict the trucks behaviour under the actual circumstances.

In this research work, an engine model is developed, to be used in such a simulation environment that is able to capture the engines behaviour, regarding torque response, fuel consumption and exhaust gas temperature. The engine to be modelled is a 13 litre, in line, six cylinder, four stroke, diesel engine with VGT (Variable Geometry Turbine) and EGR (Exhaust Gas Recirculation) including the control system. The engine works in several different modes to achieve the legislated emission standards, for example one mode for best efficiency and one to maintain high exhaust temperature so that the SCR (Selective Catalyst Reduction) can work properly. In these modes the engine performs differently in terms of torque response, efficiency and exhaust temperature. Hence, the need for this research works. The aim of this research work is to develop a model of the engine to be used for simulating translatory motion of the complete vehicle in order to evaluate gear selection, optimize the brake torque, fuel consumption and exhaust gas temperature which are based on engine speed and pedal position.

MATERIAL AND METHOD

2.1.The Simulink Library

This is one of the most important tool that would be used for the simulation of Heavy duty Diesel Engines in other to develop a computational efficient model. The SIMULINK icon is found on the MATLAB interface. The SIMULINK library is has constituent blocks that would be used in the simulation of the diesel engine. The actual design for this computational efficient model would be carried out first mathematically.

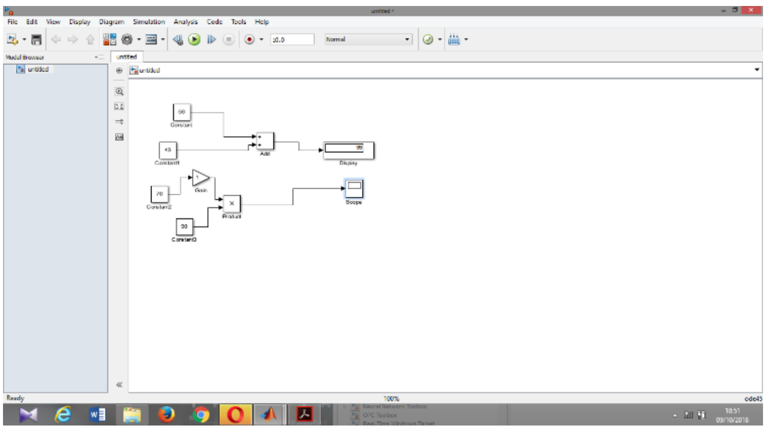


Figure 2.1. SIMULINK window (from MATLAB R2013b)

2.1.1. Mathematical Model and Method

A model of a diesel engine and its electronic control system is to be developed to capture the engines behaviour in a vehicle simulation environment. The modelled quantities are brake torque, fuel consumption and exhaust gas temperature and are based on engine speed and pedal position. In order to describe these outputs the inlet air flow and boost pressure are also modelled and used as inner variables.

The approach that was used in this research work was MARE (Mean Absolute Relative Error) and WHTC (World Harmonized Transient Cycle) that uses engine speed and desired torque as inputs to calculate set-points in inlet air mass flow. The set-point is filtered through a first order system with varying time constant and then used to limit the output torque. The output torque is also filtered through a first order system with varying time constant. An overview of the model presented in can be seen in Figure 2.

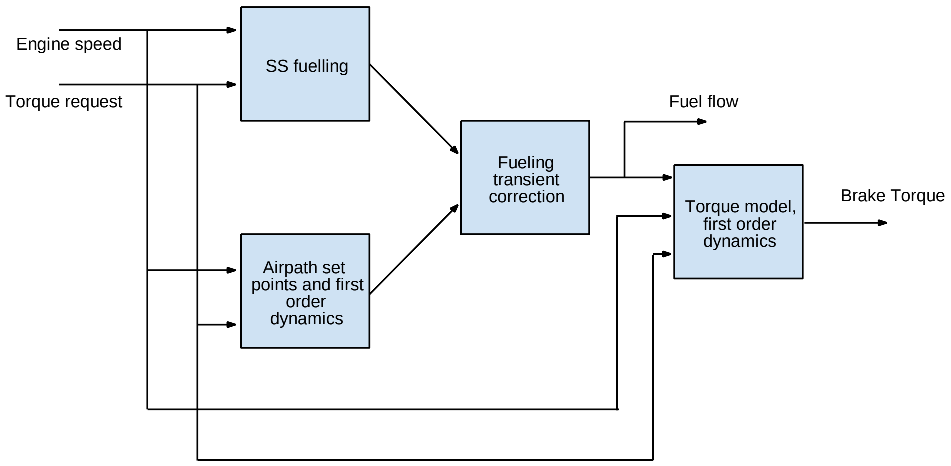


Figure 2.2. Overview of the model presented

The mathematical combustion model used is based on the model developed by Ferguson for the arbitrary heat release of fuel inducted diesel engines (Ferguson, 2006). The following equations for combustion unless otherwise noted are from Ferguson. The control volume considered for combustion is to be modelled by equation 1. The properties of the fluid in the combustion chamber are determined using the subroutines FARG and ECP. These subroutines use state variables of temperature and pressure to determine the properties of the fluid. The energy within the system is split into two sets of constituents, burned and unburned. Both are assumed to have the same pressure but temperature is not necessarily the same.

The burn rate is modelled using the Wiebe function.

$$m\frac{du}{d\theta}+u\frac{dm}{d\theta}=\frac{dQ}{d\theta}-P\frac{dV}{d\theta}-\frac{m_i h_i}{\omega} \tag{1}$$

Specific volume and energy is considered to only be only a function of temperature and pressure. Differentiating with respect to crank angle and substituting the natural logs gives the following equations.

$$\frac{dv_b}{d\theta} = \frac{v_b}{T_b}\frac{\partial \ln v_b}{\partial \ln T_b}\frac{dT_b}{d\theta} + \frac{v_b}{P}\frac{\partial \ln v_b}{\partial \ln P}\frac{dP}{d\theta} \tag{2}$$

$$\frac{dv_u}{d\theta} = \frac{v_u}{T_u}\frac{\partial \ln v_u}{\partial \ln T_u}\frac{dT_u}{d\theta} + \frac{v_u}{P}\frac{\partial \ln v_u}{\partial \ln P}\frac{dP}{d\theta} \tag{3}$$

$$\frac{du_b}{d\theta} = \left(c_{pb} - \frac{Pv_b}{T_b}\frac{\partial \ln v_b}{\partial \ln T_b}\right)\frac{\partial T_b}{\partial\theta} - v_b\left(\frac{\partial \ln v_b}{\partial \ln T_b} + \frac{\partial \ln v_b}{\partial \ln P}\right)\frac{dP}{d\theta} \tag{4}$$

$$\frac{du_u}{d\theta} = \left(c_{pu} - \frac{Pv_u}{T_u}\frac{\partial \ln v_u}{\partial \ln T_u}\right)\frac{dT_u}{d\theta} - v_u\left(\frac{\partial \ln v_u}{\partial \ln T_u} + \frac{\partial \ln v_u}{\partial \ln P}\right)\frac{dP}{d\theta} \tag{5}$$

When equations are substituted into equation 1, the new equation is of the form seen in equation 6.

$$mx\left(c_{pb} - \frac{Pv_b}{T_b}\frac{\partial \ln v_b}{\partial \ln T_b}\right)\frac{\partial T_b}{\partial\theta} + m(1-x)\left(c_{pb} - \frac{Pv_u}{T_u}\frac{\partial \ln v_u}{\partial \ln T_u}\right)\frac{\partial T_u}{\partial\theta} - \frac{\partial P}{\partial\theta}\left[mxv_b\left(\frac{\partial \ln v_b}{\partial \ln T_b} + + \frac{\partial \ln v_b}{\partial \ln P}\right)\right.$$
$$\left. + mv_u(1-x)\left(\frac{\partial \ln v_u}{\partial \ln T_u} + \frac{\partial \ln v_u}{\partial \ln P}\right)\right] m\frac{dx}{d\theta}(u_b - u_u) + u\frac{dm}{d\theta} = \frac{dQ}{d\theta} - P\frac{dV}{d\theta} - \frac{m_i h_i}{\omega} \tag{6}$$

The Wiebe function determines heat addition to the control volume during combustion. The Wiebe function is shown in equations 7 and 8. The coefficients b and n in equation 10 determine the rate of burn over the burn period (Ferguson, 2006). The coefficients can be fitted to experimental data from the given engine if data is available.

$$x = 1 - e^{-b\left[\left(\frac{\theta-\theta_s}{\theta_b}\right)^n\right]} \tag{7}$$

$$x = -\left(1 - \cos\left(\frac{\pi\ \theta-\dot{\theta}_s}{\theta_b}\right)\right) \tag{8}$$

In order to determine the mass lost during combustion across the piston rings a general equation is developed. Mass loss is only considered to be a function of engine speed.

$$m = m\ e^{-\frac{C\ \theta-\theta}{\omega}} \tag{9}$$

The heat loss is the sum of the heat flow out of the burned and unburned fluids. The only form of heat transfer considered is convection. The heat transfer coefficients are determined by the Woschni model.

$$A_b = \left(\frac{\pi b^2}{2} + 4\frac{V}{b}\right)\sqrt{x} \tag{10}$$

$$A_u = \left(\frac{\pi b^2}{2} + 4\frac{V}{b}\right)\left(1 - \sqrt{x}\right) \tag{11}$$

$$V = V_{tdc}\left(1 + \frac{CR-1}{2}\left\{1 - cos\theta + \frac{1}{\epsilon}\ \langle 1 - \sqrt{1 - \epsilon^2 sin^2\theta}\rangle\right\}\right) \tag{12}$$

The equation for the specific volume of the system is found by differentiating equation 4 and substituting 5, 6 and 12 into it.

$$\frac{1}{m}\frac{dV}{d\theta}-\frac{V}{m^2}\frac{dm}{d\theta}=x\frac{dv_b}{d\theta}+(1-x)\frac{dv_u}{d\theta}+(v_b-v_u)\frac{1}{m}\frac{dx}{d\theta}\frac{dV}{d\theta}+\frac{VC}{m\omega}=x\frac{v_b}{T_b}\frac{\partial\ln v_b}{\partial\ln T_b}\frac{\partial T_b}{\partial\theta}+$$
$$(1-x)\frac{v_u}{T_u}\frac{\partial\ln v_u}{\partial\ln T_u}\frac{\partial T_u}{\partial\theta}+\left(x\frac{v_b}{P}\frac{\partial\ln v_b}{\partial\ln P}\frac{dP}{d\theta}+(1-x)\frac{v_u}{P}\frac{\partial\ln v_u}{\partial\ln P}\frac{dP}{d\theta}\right)\frac{dP}{d\theta}+(v_b-v_u)\frac{dx}{d\theta} \quad (13)$$

The unburned fluid entropy leaving the system is seen in equation 14. The derivate of entropy with respect to crank angle is seen in equation 15. When combined they form equation 16.

$$\dot{Q}_u=\omega m\,(1-x)T_u\frac{\partial S_u}{\partial\theta} \quad (14)$$

$$\frac{\partial S_u}{\partial\theta}=\left(\frac{Cp_u}{T_u}\right)\frac{\partial T_u}{\partial\theta}-\frac{v_u}{T_u}\frac{\partial\ln v_u}{\partial\ln P}\frac{dP}{d\theta} \quad (15)$$

$$Cp_u\frac{\partial T_u}{\partial\theta}-v_u\frac{\partial\ln v_u}{\partial\ln P}\frac{dP}{d\theta}=-h\frac{\left(\frac{\pi b^2}{2}+4\frac{V}{b}\right)}{\omega m}-\frac{1-\sqrt{x}}{1-x}(T_u-T_w) \quad (16)$$

MATLAB would be used to solve the system of equations (ODE 45). The coefficients A, B, C, D and E are used to simplify the equation layout. Equations 3.17 through 3.21 use the coefficients to determine the change in pressure, temperature, work, heat transfer, and heat loss at each position crankshaft position.

$$A=\frac{1}{m}\left(\frac{dv}{d\theta}+\frac{VC}{\omega}\right) \quad (17)$$

$$B=h\frac{\left(\frac{\pi b^2}{2}+4\frac{V}{b}\right)}{\omega m}\left[\frac{dv_b}{Cp_u}\frac{\partial\ln v_b}{\partial\ln T_b}\sqrt{x}\frac{(T_b-T_w)}{T_b}+\frac{v_u}{Cp_u}\frac{\partial\ln v_u}{\partial\ln T_u}-\sqrt{x}\frac{(T_u-T_w)}{T_u}\right] \quad (18)$$

$$C=-(v_b-v_u)\frac{dx}{d\theta}-v_b\frac{dx}{d\theta}\frac{\partial\ln v_b}{\partial\ln T_b}\frac{h_u-h_b}{Cp_bT_b}\left[\frac{dx}{d\theta}-\frac{(x-x^2)C}{\omega}\right] \quad (19)$$

$$D=x\left[\frac{{v_b}^2}{Cp_bT_b}\frac{\partial\ln {v_b}^2}{\partial\ln T_b}\left(\frac{h_u-h_b}{Cp_bT_b}\right)^2-\frac{v_b}{P}\frac{\partial\ln v_b}{\partial\ln P}\right] \quad (20)$$

$$E=(1-x)\left[\frac{{v_u}^2}{Cp_uT_u}\left(\frac{\partial\ln v_u}{\partial\ln T_b}\right)^2-\frac{v_u}{P}\frac{\partial\ln v_u}{\partial\ln P}\right] \quad (21)$$

The equations above would thus be used to find the given parameters brake torque, fuel consumption and exhaust gas temperature which are based on engine speed and pedal position and also, find their optimal values while using SIMULINK to simulate the various sub-models of the main Diesel Engine model.

The outputs would thus enable gear shift optimization over three variables, torque for vehicle acceleration, fuel consumption for efficiency and exhaust temperature to maintain high efficiency in the exhaust after treatment system.

Apart from the Equations numerically developed from related literatures, the below equations were industrially analysed and necessary for the modelling of the Diesel Engine in other to optimize the brake torque, fuel consumption and exhaust temperature. These equations are described and applied in the below sub sections 2.3.2, 2.3.3 and 2.3.4.

$$\dot{m}_{fuel} = \theta_1 P + \theta_2 N + \theta_3 T + \theta_4 \quad (22)$$

$$V_M(\theta) = \frac{1}{M}\sum_{i=1}^{M}\left(\dot{m}_{fuel}(i|\theta) - \dot{m}_{fuel,meas}(i)\right)^2 \quad (23)$$

$$Mbrake = Mind - Mloss(N) \quad (24)$$

$$\dot{m}_{air} c_p (T_{ini} - T_{exh}) + \dot{m}_{fuel\rho LHV} - P_{eng} - P_{heat} = 0 \quad (25)$$

$$T_{exh,SS} = \theta_1 \dot{m}_{fuel} + \theta_2 P_{ind} + \theta_3 \dot{m}_{air} + \theta_4 W + \theta_5 \quad (26)$$

$$T_{exh}(k) = \lambda S_{exh1}(k) + (1-\lambda) S_{exh2}(k) \quad (27)$$

2.2. Simulation Models

2.2.1 Simulink scheme of a Diesel Engine Model

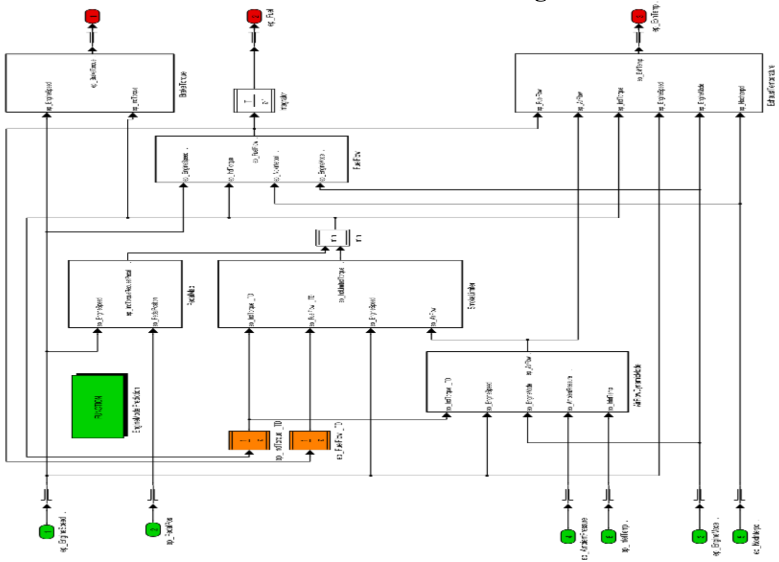


Figure 2.3. Simulink scheme of Engine Model.

From Figure 3, all other models are sub models to the above Simulink scheme of a Diesel Engine Model. This is gradually explained in the sub-sections below and how the operate.

2.2.2 Sub-model for the Fuel Flow

To know how efficient the engine is running the engine model needs to calculate the fuel consumption. The fuel injection system is of common-rail type and basically consists of a chamber containing fuel under high pressure which can be sprayed in to the cylinder at a desired time and flow rate. In this section a model over the fuel flow is presented. The in and out ports are stated in Table 2.1.

Table 2.1 In and out-ports of the fuel flow sub-model

Port	*In/Out*	*Unit*	*Dependency*
Engine Speed	*In*	*RPM*	-
Torque Demand	*In*	*Nm*	-
Engine Mode	*In*	-	-
Power Demand	*In*	*RPM·Nm*	-
Inlet Temperature	*In*	*◦C*	-
Fuel Flow	*Out*	*Kg/s*	*Smoke Limiter*

2.2.2.1. Implementation of the Fuel Flow Sub-model

The dynamics in the fuel injection system are very fast (the fuel arrives in the cylinders in the same cycle as the control signal is sent from the EECU) and are therefore neglected.

Even the torque response from the injected fuel is fast enough to be neglected as the burned fuel in a certain cycle delivers the desired force on the piston the same cycle it is injected.

The actual fuel flow is approximated with the, by the EMS, requested fuel flow. This isolates the model to describe the behaviour of the EMS concerning fuel flow. To use the same calculations as the EMS would be too time consuming because it uses inputs from many sensors and the function is relatively demanding to compute. The timing, i.e. when and how the fuel is injected, is also calculated at the same time as the fuel flow in the EMS. In the model the timing itself is not interesting but a change in timing affects the behaviour of the engine. To get more heat in the exhaust gases (engine in heat mode described in Chapter 1) the injection timing is changed from its optimum. This causes the efficiency to decrease and therefore the amount of injected fuel has to increase for the engine to produce the same torque as before. The timing is also changed to get the engine to produce a different amount of NO_x.

Different ways of controlling fuel injection electronically has been done. One common way is to use mapped values depending on operating point. In this model the fuel flow is modelled as a linear function of the requested power, requested torque and actual engine speed as seen in Equation (22). The corresponding Simulink implementation is seen in Figure 2.3.1a and 2.3.1b.

This way is chosen because the number of function parameters is far less than all the mapped values required which will save memory utilisation. One advantage with the map-based solution is that the model will cover a larger span of operating points accurately. For this model the fuel flow at engine speed near idle and maximum and engine torque near zero are not very important as the model is used mostly in normal driving conditions.

Where the engine power has the largest impact on the fuel flow model, the engine speed and torque makes smaller adjustments. Several possible functions are tested to see which one gives the best result but the function in Equation (22) is shown to be the best concerning computation time and ease of finding parameters.
The parameters in Equation (22) differs when the engine runs in different modes and produce different amount of NO_x. Therefore different parameters are estimated for the different modes and for 100% and 0% NO_x production for each mode. This gives six sets of function parameters. When using the model for simulation the model selects the parameters for the actual mode and interpolates the parameters according to NO_x production and keeps the parameters the same throughout the whole simulation.

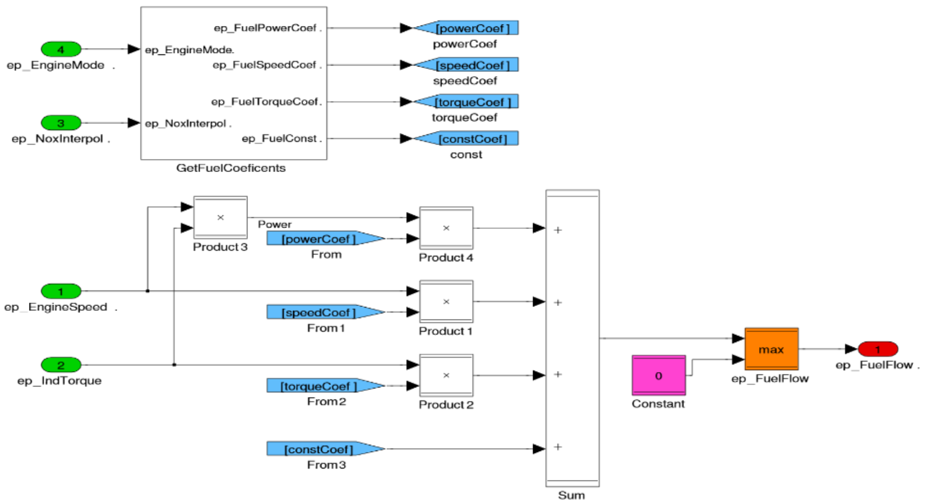


Figure 2.3.1a. Simulink scheme of FuelFlow, The fuel flow is modelled as a linear function of indicated power, indicated torque and engine speed, equation (22).

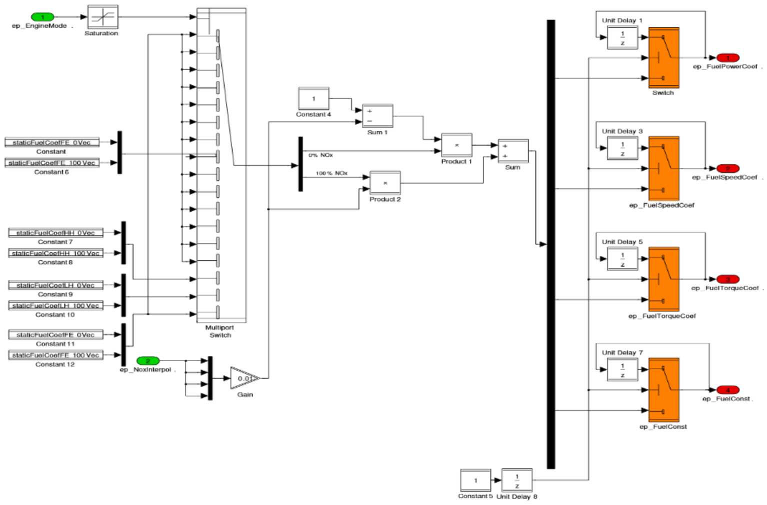


Figure 2.3.1b. Simulink scheme of the sub-model GetFuelCoefficients in Figure 2.3.1a initializes the model coefficients depending on NO_x production and engine mode.

2.3 Sub-Model for the Brake Torque

To get the brake torque from the indicated torque the mechanical losses in the engine has to be subtracted. The mechanical loss consists of auxiliary devices, e.g. climate control and cooling fan, and friction in the engine.

It is common to include pumping losses when modelling SI engines but in diesel engines they can be neglected due to absence of a throttle. The in- and out-ports to the sub-model can be seen in Table 2.2.

Table 2.2. In and out-ports of sub-model Brake Torque

Port	In/Out	Unit	Dependency
Engine Speed	In	RPM	-
Indicated Torque	In	Nm	-
Brake Torque	Out	Nm	-

2.3.1 Implementation of the Brake Torque Sub-Model

An easy way to model these losses is with a second degree polynomial suggested the equations above. In this model mapped values are used for the torque losses, as a function of engine speed as seen in Equation (24) and Figure 2.3.2.

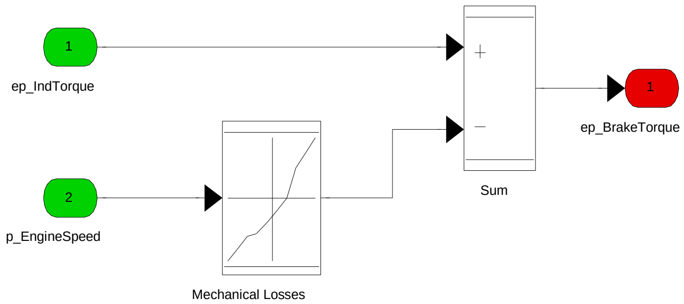


Figure 2.3.2: Simulink scheme of sub-model Brake Torque, corresponds to Equation (24). Subtracts losses from indicated torque and returns brake torque.

2.3.3 Exhaust Temperature

All of the energy from the injected fuel that isn't used to push the piston down in the cylinder will end up as heat that is transported from the cylinder in different ways. Some of the heat will pass through the cylinder head and walls and be transported away through the cooling water, engine oil or directly to the surrounding air. The rest of the heat will leave the combustion chamber through the exhaust gases. The in- and out ports of the model are stated in Table 2.3.

Table 2.3. In and out-ports of the exhaust temperature sub-model

Port	In/Out	Unit	Dependency
Fuel Mass Flow	In	kg/s	
Indicated Power	In	RPM, Nm	·
Air Mass Flow	In	kg/s	
Indicated Torque	In	Nm	
NO_x production	In	%	
Engine Mode	In	-	
Inlet Temperature	In	◦C	
Exhaust Temperature	Out	◦C	

2.3.4. Implementation of the Exhaust Temperature Sub-Model

In Jesper RitzÃ (2012) the exhaust temperature is modelled using power balance of the combustion chamber to calculate how much the intake air temperature rises in a spark ignited engine. This power balance is seen in the first law of thermodynamics, Equation (25). The heat losses, P_{heat}, is in Jesper RitzÃ (2012) an empirical function of air and fuel mass flow, spark timing and engine speed. This is the only term, except the exhaust temperature, T_{exh}, that isn't measured.

In the above related literature, the exhaust temperature is modelled as a sum of three first order dynamic systems with engine speed, AFR and spark timing as inputs for each respective system. Both these two models are for spark ignited engines but the approaches are interesting for diesel engines as well. The injection timing affects the combustion almost like the spark timing. The concepts used in these two models are interesting because they are relatively easy to calculate and optimize.

The first law of thermodynamics Jesper RitzÃ (2012) seen in Equation (25) is used to describe the power balance in the combustion chamber. The known variables are injected fuel and the power output from the engine. Left to determine is how much power that leaves the engine in form of heat losses through the cylinder wall and head, P_{heat}, and the temperature of the air entering the cylinders, T_{inl}. These two terms are not explicitly modelled. The steady state exhaust temperature, $T_{exh,SS}$, is modelled as a linear function of fuel mass flow, $\dot{m}_{fuel}$, indicated power, P_{ind}, air mass flow, $\dot{m}_{air}$ and a mapped function of indicated torque and engine speed, W, seen in Equation (26). The Simulink implementation is seen in Figure 2.3.4a where output from the map called exhMap is W.

The coefficients in Equation (26) differ when the engine runs in normal or heat mode or produce different amount of NO_x. Therefore different coefficients are estimated for the different modes and for 100% and 0% NO_x production. This gives four sets of function coefficients. When using the model for simulation the model selects the coefficients for the actual mode and interpolates them according to NO_x production. These are kept the same throughout the whole simulation. The Simulink model of the parameter selection is seen in Figure 2.3.4b.

Equation (27) describes the state space model handling the dynamics of the exhaust temperature and is the equations implemented in the Simulink sub model in Figure 2.3.4c. $T_{exh,SS}$ is the steady state exhaust temperature calculated in Equation (26) and is the input to the dynamic sub-model. $S_{exh,1}$ and $S_{exh,2}$ are the two states that sums together, with the ratio λ, to the exhaust temperature in Equation (27). Equation 27 is thus sub implemented and depends on these two equations for its definition and value.

$$S_{exh1}(k+1) = \left(1 - \frac{T_s}{T_1}\right) S_{exh1}(k) + \frac{T_s}{T_1} T_{exh,SS}(k) \tag{28}$$

$$S_{exh2}(k+1) = \left(1 - \frac{T_s}{T_2}\right) S_{exh2}(k) + \frac{T_s}{T_2} T_{exh,SS}(k) \tag{29}$$

2.3.4.1 Calibration

Calibration is done in steady state measurements where the indicated torque is logged (from the EECU) and the brake torque is measured. This is done at several different engine speeds and for every engine speed a value of M_{loss} is estimated using least square error minimization. To estimate the coefficients Θ in Equation (26) the engine is run at steady state at several different operating points for different modes and with different NO_x production. The exhaust temperature and the input signals for the model are measured at these operating points. The least square cost function to minimize is seen in Equation (18), where M is the number of measurements and i is the operation point.

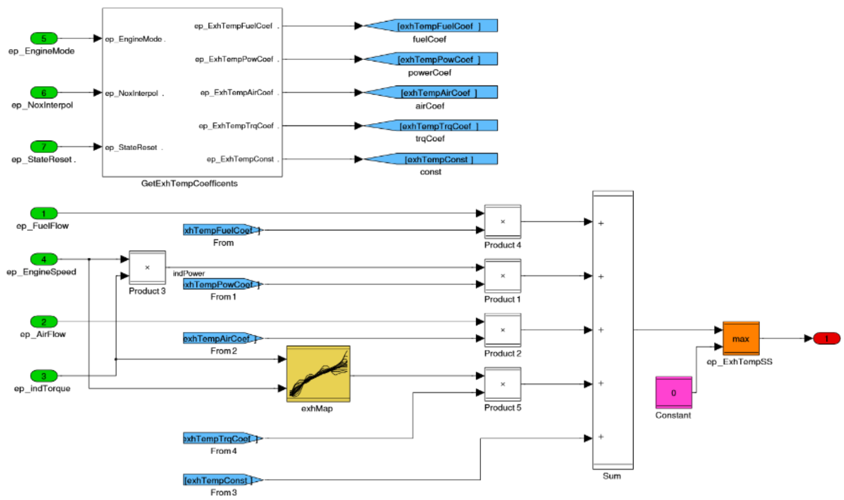


Figure 2.3.4a: Simulink scheme of the steady state exhaust temperature, implementation of Equation (26). The output is input to the Simulink scheme in Figure 2.3.4c.

The parameter to determine in the dynamic part of the model, Figure 2.3.4c, is the time constants; τ_1 and τ_2 for both first order systems and the ratio between their outputs. The same criterion as in (2.3.4c) is used for optimizing the dynamic model.

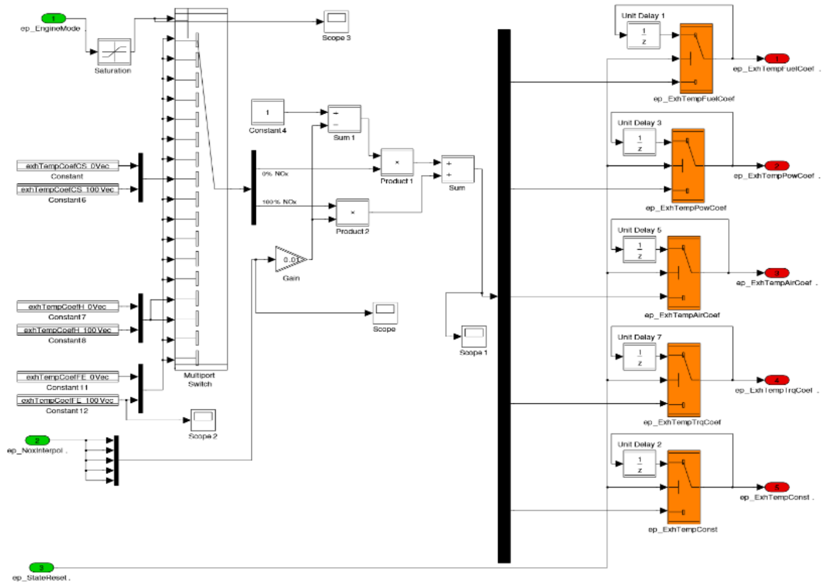


Figure 2.3.4b: Simulink scheme of the block GetExhTempCoefficients in Figure 2.3.4a. Initializes the model coefficients depending on NO_x production and engine model

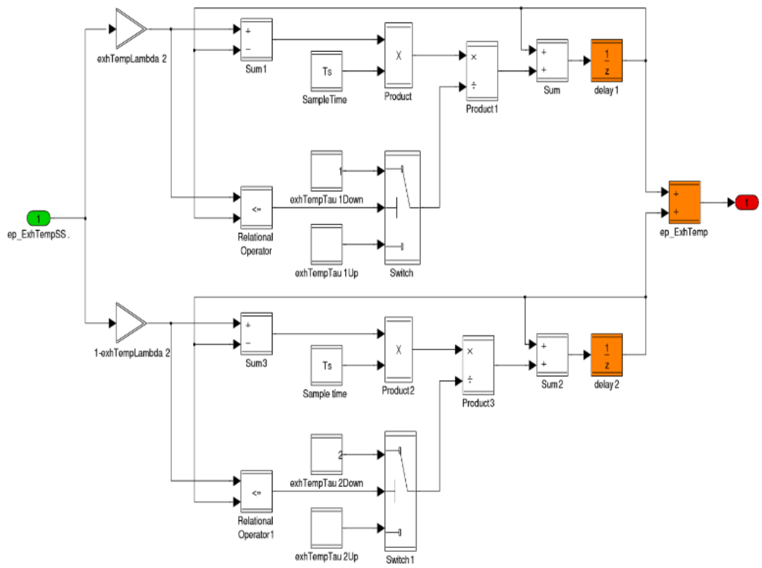
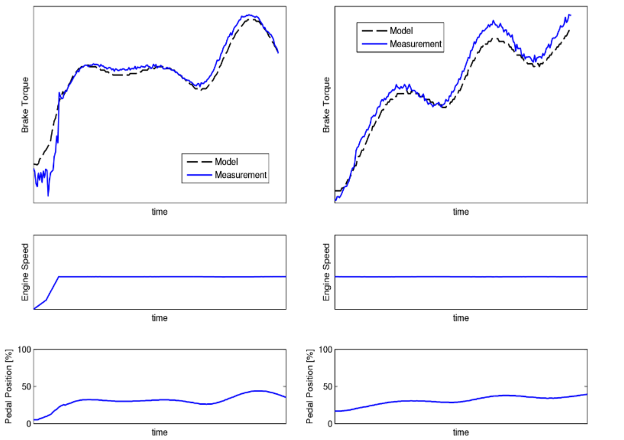


Figure 2.3.4c: Simulink scheme of the dynamic exhaust temperature, implementation of Equation (27). A sum of two first order systems that filters the steady state exhaust temperature from the Simulink scheme in Figure 2.3.4a.

RESULTS AND DISCUSSION

3.1 Brake Torque

Figure 1 and 2 are the result from four simulations compared to measurement of torque transients can be seen. In Figure 3.1 the AFR does not reach the limit in the smoke limiter, neither during data collection in the real system nor during simulation. In Figure 4.2 there are greater steps in pedal position and the AFR limit is reached both during data collection and simulation. The torque measurements are not corrected for rig inertia i.e. when the engine accelerates the rig measures a lower output torque than the actual. The MARE is 6.3, 4.6, 6.8 and 4.2% for simulations in 1(a) - (b) - 2(a) - (b) respectively.



(a) (b)

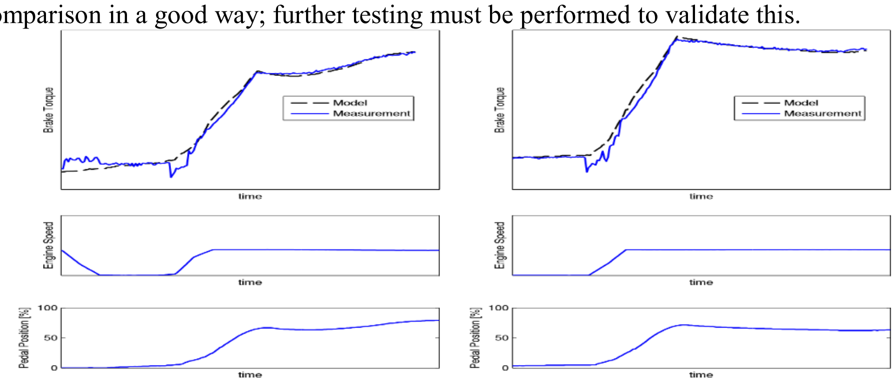
Figure 1. Brake torque transients in the BLB-cycle where the smoke limiter is active during the transients

To evaluate the torque model comparison with only measurements are not sufficient. In which context the model should be used and the external uncertainty that affects the model has to be taken in to consideration. Assume that an uncertainty in the estimated weight of the vehicle of 10% is translated to an uncertainty of inertia at the flywheel. The difference in torque that would be needed to accelerate the engine, see Figure 4.3, would be in the same range as the error between modelled and measured brake torque.

3.2 Fuel Consumption

In Figure 4.4 the fuel consumption from two simulations can be seen, in Figure 4.4a and 4.4b the relative error is 7.8% respectively 1.0%. The fuel consumption model's purposes is to be able to evaluate the fuel efficiency in different gear shifts.

It is important that the mutual order and ratio of fuel efficiency between different gears shifts are correct not the absolute value. There has been no data available to do this comparison in a good way; further testing must be performed to validate this.



(a) (b)

Figure 2. Brake torque transients in the BLB-cycle where the smoke limiter is active during the transients

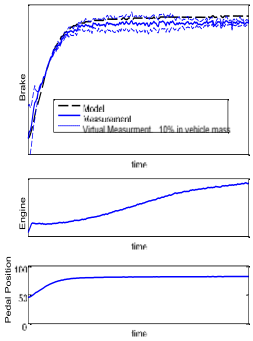
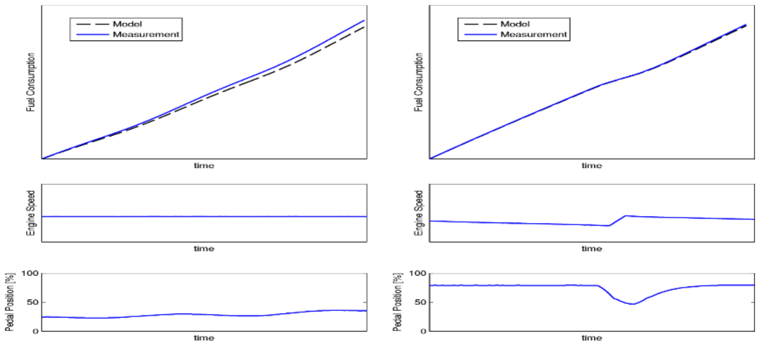


Figure 3: Shows how ±10% in mass affects the brake torque with given acceleration.



(a) (b)

Figure 4. Fuel consumption in two sections of the BLB-cycle

3.3 The Exhaust Temperature

The exhaust temperature model is validated by feeding the input of the exhaust temperature Simulink model with measured signals and compares the output from the model with measured exhaust temperature. Figure 4.5 shows the simulation result compared to measured exhaust temperature.

Figure 4.6 shows the simulation result compared to measured steady state exhaust temperature for one mode. When simulating the model for six different mode configurations the total result is an MARE of 5.4%. For this validation the dynamics of the model are not activated because the measurement points are not time dependent (steady state engine run). This validation is done to see if the errors derives from the steady state model or the dynamic model afterwards. To validate the dynamic model the WHTC is used and the model is run at 10 Hz. The cycle is divided into 20 second simulation intervals. The absolute difference between the last measured and simulated value for every simulation is considered. The maximum difference is 38^{o} C and the mean difference for all simulations is $22\ ^{o}$ C .

The MARE for the whole cycle is 5.8%. If this result is good enough depends on the application which at this time is not specified in detail.

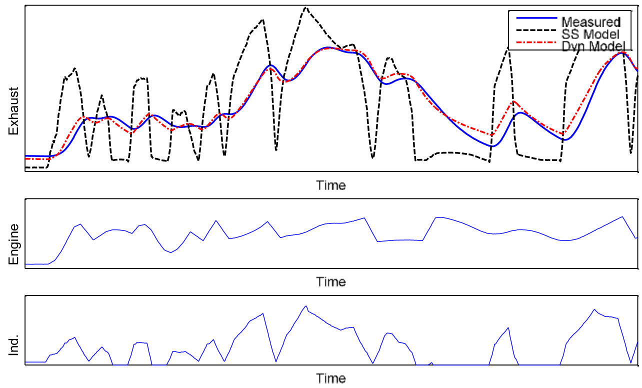


Figure 5. Simulated temperature compared to measured exhaust temperature

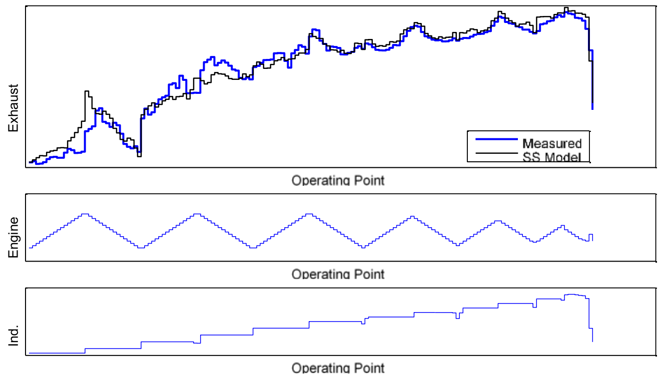


Figure 6. Simulated temperature compared to measured steady state exhaust temperature

CONCLUSION

The model performs well consider the computational efficiency. The brake torque, fuel consumption and exhaust gas temperature have a mean absolute relative error lower than 6.8%, 7.8% and 5.8% respectively. The three outputs from the model describes the modelled system well enough to continue with testing in the embedded system.

Recommendation

Below some interesting suggestions are discussed for future work to improve the model

Turbo dynamics at high altitudes.

The turbo dynamics changes when the engine drives in high altitude due to reduced density in the ambient air. The pressure build up gets slower at high altitudes and this affects the torque response in a negative way.

Due to absence of high altitude data with the engine used for modelling no implementation and evaluation on this has been done.

EGR

The air mass flow (as function of pressure and engine speed) is modelled from steady state measurement in intake air flow and not from the total amount of gas that enters the combustion chamber. How large amount of the gases that goes in to the cylinder that is EGR is hard to estimate. A model over the EGR control system and how much EGR that enters the intake manifold would greatly improve the air mass flow estimate in very sharp transients which would give a better AFR estimate, which in turn would provide a better torque estimate.

NO_x

It would be interesting to model the amount of NO_x the engine produces to be able to select gears that minimizes NO_x-production when the SCR is cold.

Exhaust Temperature

It would be interesting to try a solution where a sum of several first order systems with different signals is used as inputs. The input signals could be all of the inputs to the sum block in the steady state exhaust temperature Simulink model (Figure 4.6). An alternative or complement to this could be to make the time constants in the current model dependent of some variable, e.g. engine speed. It would also be interesting to investigate the physical relations that affects the exhaust temperature more in detail. This to be able to implement the non-linearity better and to see if some other quantity is needed to be modelled in order to describe the exhaust temperature accurately.

Fuel Flow

To improve the fuel flow accuracy the fuel flow could be mapped in a lookup table for the operating points and the different modes.

An interesting alternative to different lookup tables for different modes could maybe be to have a function based on mode and NO_x - production that compensates a base lookup table to save memory utilization.

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RAČUNARSKI MODEL POTROŠNJE GORIVA I TEMPERATURE IZDUVNIH GASOVA TEŠKOG DIZEL MOTORA UPOTREBOM MATLAB/SIMULINK

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Abstrakt. Model dizel motora i njegovog elektronskog sistema upravljanja razvijen je zbog istraživanja ponašanja motora u simulacionom okruženju vozila. Modelirani radni parametri (veličine) dizel motora su: obrtni moment kočioni, potrošnja goriva i temperatura izduvnih gasova. Ovi parametri imaju vrednosti zasnivane na broju obrataja radilice motora i položaju komande pedale za gas .

Da bi se opisale ove predhodne izlazne veličine, protok ulaznog vazduha i potisni pritisak gasova u motoru takođe su modelirani i koriš e ni kao unutrašnje promenljive veličine. Model se primenjuje za vozilo u upravljačkoj jedinici koja ima ograničene računske performanse. Da bi model bio računski efikasniji, model se u osnovi sastoji od računskih polinoma, ili odgovaraju ih algoritama. Sistemi jednačina prvog reda koriš e ni su za opisivanje dinamike protoka vazduha i temperature izduvnih gasova. Izlazne veličine omogu a vaju optimizaciju menjača vozila preko tri promenljive: obrtni momenat za ubrzanje vozila, potrošnju goriva za efikasnost i temperaturu izduvnih gasova, kako bi se održala visoka efikasnost u izduvnom sistemu nakon tretmana.

Model teškog dizel motora beleži nisku učestalost dinamike modelovanih veličina u zatvorenoj petlji motora i njegovog elektronskog sistema upravljanja. Model se sastoji samo od tri stanja: jednog za stvaranje pritiska u usisnom sistemu i dva stanja za modeliranje temperature izduvnih gasova.

Model je upoređen sa izmerenim podacima kod ispitivanja motora (prikaz INNOSON NIG. LTD.), a srednja apsolutna relativna greška bila je niža od 6,8%, 7,8% i 5,8% za obrtni momenat sile kočenja, potrošnju goriva i temperaturu izduvnih gasova . Dobijeni rezultati se smatraju dobrim, obzirom na jednostavnost prikazanog modela.

Ključne reči: *Računski modeli, obrtni kočioni momenat, potrošnja goriva, temperatura izduvnih gasova, teški dizel motor.*

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EFFECT OF MOISTURE CONTENT ON THE THERMAL PROPERTIES OF HORSE-EYE BEAN SEEDS RELEVANT TO ITS PROCESSING

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***Abstract*:** The specific heat, thermal conductivity and thermal diffusivity of the Horse-Eye bean (*Mucuna sloanei*) were determined as a function of moisture content using the method reported by A.O.A.C (2000). The sample varieties used were the Big Sized and the Small Sized Horse-Eye bean. The specific heat and the thermal conductivity were measured using a Bomb Calorimeter. The thermal diffusivity was calculated from the measured specific heat, thermal conductivity and bulk density of the samples. Within the moisture range of 10.5% to 16.87% (b.b), the specific heat, thermal conductivity and thermal diffusivity varied with the moisture content. Results showed that the specific heat, thermal conductivity and thermal diffusivity of the Horse-Eye bean seeds ranged from 116.76 to 203.29 kJ/kgK; 21.07 to 32.23 W/m^{o}C; and 3.12 x 10^{-7} to 9.19 x 10^{-7} m^2/s, for the Big Sized varieties, and 112.06 to 194.61 kJ/kgK; 19.85 to 24.08 W/m^{o}C; and 3.05 x 10^{-7} to 6.71 x 10^{-7} m^2/s, for the Small Sized varieties as the moisture content increases from 10.5% to 16.87%. Regression analysis were also carried out on the thermal properties of the Horse-Eye bean varieties and moisture content, and there was positive relationship between the parameters. There were significant effects of moisture content ($p < 0.05$) on all the parameters conducted. The findings and the data generated will create an impact in the food processing industries for Horse-Eye bean.

Keyword: *Specific heat, Thermal conductivity, Thermal diffusivity, Horse-Eye Bean flour.*

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INTRODUCTION

Agricultural and food material are biological and have certain unique characteristics and undergo various unit operation from pre-harvest to post harvest processing, formulation, preservation, packaging, storage distribution, domestic storage and finally consumption. During all these processes agricultural material display different behavior. Therefore, understanding the engineering properties of agricultural material at any condition are important in order to solve problems associated with designing and selecting the modes of preservation, packaging, processing, storage, marketing and consumption.

Thermal properties of agricultural materials and foods need to be known to better understand their nature and to be able to develop new technologies [16]

Thermal processes such as pasteurization, concentration, drying, heating, cooling, sterilization, thawing, cooking, refrigeration, freezing, and evaporation are frequently used in food processing, transportation, and preservation operations, [11];[9].

Knowledge of thermal properties of foods is thus crucial not only for equipment design but also for the prediction and control of various changes occurring in foods during heat transfer processes associated with storage and processing, [8] .

Thermal properties data are required both for existing foods and for new products and processes. Besides processing and preservation, thermal properties also affect sensory quality of foods as well as energy savings from processing [8]. Horse-Eye bean (mucuna sloanei), is one of the over numerous species of shrubs and climbing vines that is generally accepted due to its important benefits to humans and their environment. It is a legume mainly found in the tropical and sub-tropical part of the world, but mainly in Nigeria. In Nigeria, it is called 'ukpo' by the Igbos, 'karasuu' by the Hausas, 'yerepe' by the Yorubas, and 'ibabat' by the Efiks, [6]. It is mainly used as a food thickener in Nigeria, [11]. It contains phosphorus, but very little in the supply of iron and calcium [14]. Horse-Eye bean (mucuna sloanei), according to previous researches carried out on its nutritional content, it is known to contain 20-25% of crude protein, 43.5-49.0% carbohydrate, 25.0-27.4% of crude fiber, 5.05-7.0% fat, and 6.46-14.0% of moisture content, [2]. It contains LDOPA (a chemical that is made and used as part of the normal biology of humans and some animals and plants) a neuro transmitter that is used to treat Parkinson disease [12]. Due to its gelatization properties and gummy texture, mucuna sloanei is used as soup recipes in eating garri, pounded yam and fufu [13]. Its commercial, nutritive, medicinal and pharmaceutical values can never be over emphasized. In order to explore all these benefits of this agricultural product, (Horse-Eye bean), there is need to process it into different food formulations and food products. Processing of Horse-Eye bean involves different thermal treatment. The seed kernel will then be parboiled, dried, grounded into fine powder and packaged in fanciful bags for marketing or use for food recipes mainly for soup thickening. The existing method of carrying out this above processing procedures are task demanding, labour intensive, time consuming and very wasteful. Therefore, it is very necessary to properly understand the some of the thermal properties of this Horse-Eye bean that are relevant in the designing and fabrication of its postharvest processing machines and equipment.

Thus, the objective of this study was to determine the effect of moisture content on the thermal properties of Horse-Eye bean seeds that are relevant to its processing, storage and handling. The concerned properties were thermal conductivity, thermal diffusivity, and specific heat.

MATERIAL AND METHODS

Sample Preparation

The Horse-Eye bean samples used for this research work were collected from a local farm at a stable storage moisture. The variety seeds of the Horse-Eye bean collected were properly cleaned and sorted to select viable seeds. The sample varieties used for the research are described as; The Big Sized variety (Ukpo Nnukwu) and The Small Sized variety (Ukpo Ntakiri). These sample varieties were further hydrated to acquire more three different moisture content levels at which the tests were carried out. The conditioned seeds were packaged in an airtight container with proper labelling and then moved to the laboratory were thermal properties were analyzed. A total of 1000 grains were used for the experiments.

Determination of the Thermal Properties of Horse-Eye Bean Seeds

Determination of the Specific Heat of Horse-Eye bean

Association of Official Agricultural Chemists [1] approved method was used. This was done with bomb calorimeter of model XRY-1A made from Shanghai Changi, China. It involves in igniting the sample in oxygen bomb calorimeter under a high pressure of oxygen gas. The heat energy that was released was absorbed by the surrounding water and this was used to estimate the energy value of the sample.1g of the sample was pelleted and turned in the oxygen bomb calorimeter. The heat of combustion was calculated as the gross energy using the method as approved by [1];

$$Energy\ Content\ = \frac{E\Delta T - 2.3B - V}{g}\left(\frac{KJ}{KG}\right) \tag{1}$$

Where; E = Energy equivalent of the calorimeter = 13039.308; ΔT = Temperature rise;

B = Length of burnt wire; V = Titration volume; G = Weight of the sample.

Determination of the Thermal Conductivity of Horse-Eye bean

The thermal conductivities of the Horse-Eye bean sample varieties were carried out using the line heat source probe approach method on non-stable state heat conduction. This approach is accessible, speedy and appropriate for small product samples. For sample food and agricultural materials, this approach has regularly been utilized in current times for the measurement of thermal conductivity [10]; [4].

The equipment comprises of an ammeter and voltmeter for the documentation of current and voltage correspondingly. A direct current (DC) power source was applied to supply the heat source.

Current and voltage of 0.7A and 4.5 ±0.5V correspondingly were applied all through the experimentation. In the system, was a regulator to alter challenge in the circuit in adequate to accomplish the anticipated current for the experimentation. The prepared samples of certain moisture content were permitted to heat up to room temperature. After weighing the sample, it was placed inside the product sample hold container of 2cm diameter, 7±0.5cm length and 0.2cm thickness. A heating coil was positioned in the center of the sample and joined outwardly to the power supply. The temperature gauge was implanted inside the product sample hold container and then the switch turned on. Taking of the temperature was carried out immediately after the product sample and sample hold cannister had attained a temperature of 30°C. The current and voltage evaluations were regulated to 0.7A and 4.5 ± 0.5V, correspondingly and utilized as heat source for the product sample. Temperatures were documented at consistent periods of 30seconds for 40minutes for each product sample. The experimentation was repeated four times on each moisture content level and documented accordingly. A graph of temperature variance at the intervals took into consideration T_2-T_1 and this resulted to the graph plotting of the average logarithms of the conforming phase ratio $\left(ln\frac{\theta_2}{\theta_1}\right)$. Thus, the graph slope, S, was calculated from the straight-line segment of the graph which is given as reported by [15];

$$S = \frac{Q}{4\pi\Delta T} \tag{2}$$

Hence, thermal conductivity is determined as,

$$K = \frac{Q}{4\pi\Delta T} \tag{3}$$

Where; K = Thermal conductivity (W/m°C); Q = Power rating of the calorimeter (J); T = Change in temperature (k).

Measurement of the Thermal Diffusivities of Horse-Eye bean.

The thermal diffusivities *(α)* of the Horse-Eye bean were calculated from the experimentally calculated results of the specific heat, C_p, the thermal conductivity, k, and the bulk densities, *ρb,* of the NERICA sample varieties using the equation as reported by [4]:

$$\alpha = \frac{K}{\rho_b\, c_{Pb}} \tag{4}$$

Where α is the thermal diffusivity ($m^2\ s^{-1}$), k is the thermal conductivity ($W\ m^{-1}\ {}^oC^{-1}$), C_p is the specific heat ($Jkg^{-1}\ {}^oC^{1}$), and ρ is the bulk density ($kg\ m^{-3}$).

Data Analysis

All the thermal properties parameters were determined at three different moisture content level, and the mean values calculated for three replications at each moisture content level.

Data were analyzed using the Statistical Analysis, Least Significant Difference (LSD) among means and was calculated at 5% significant level ($p < 0.05$) interval.

RESULTS AND DISCUSSION

Table 1. Thermal Properties of Horse-Eye Bean varieties at different moisture content and at the temperature range of 50 to 547°C

Moisture Content (%)	Sample Variety	Specific Heat (kJ/kgK)	Thermal Conductive (W/m°C)	Thermal Diffusivity (x 10^{-7} m^2/s)
10.5	Big Sized (Nnukwu)	116.76 (0.02)	21.07 (0.66)	3.21 (0.68)
	Small Sized (Ntakiri)	112.06 (1.01)	19.85 (2.08)	3.05 (0.04)
13.2	Big Sized (Nnukwu)	130.90 (1.00)	26.03 (5.16)	5.34 (0.02)
	Small Size (Ntakiri)	128.22 (1.99)	22.89 (0.03)	4.68 (0.02)
16.87	Big Sized (Nnukwu)	203.29 (0.99)	32.23 (0.11)	9.19 (0.01)
	Small Sized (Ntakiri)	194.61 (1.01)	24.08 (0.99)	6.71 (0.53)

N.B: Numbers in Parenthesis represents the standard deviation.

Table 2: Relationships between the Thermal Properties of Horse-Eye Bean samples with moisture content and temperature.

Variety	Equations	
	Big Sized (Ukpo Nnukwu)	Small Sized (Ukpo Ntakiri)
Specific heat	$c = 13.088MC + 28.44T$, $R^2 = 0.9879$	$c = 13.088MC + 28.44T$, $R^2 = 0.9879$
Thermal Conductivity	$k = 2.0305MC + 2.4961T$, $R^2 = 0.9716$	$k = 0.6458MC + 13.537T$, $R^2 = 0.8914$
Thermal Diffusivity	$\alpha = 0.8712 \times 10\text{-}7\ MC + 5.702T$, $R^2 = 0.98$	$\alpha = 0.6241 \times 10\text{-}7\ MC + 3.5228T$, $R^2 = 0.9998$

Note: ***c*** = specific heat kJ/kg°C; ***k*** = thermal conductivity (W/m°C), ***α*** =Thermal Diffusivity (x $10^{-7} m^2/s$);**MC** = moisture content, %; ***T*** = temperature, °C.

The Specific Heat

The specific heat of the flour sample presented in Table 1 and Figure 1, showed that the specific heat of Big and Small sized Horse-Eye Bean seeds increased from 166.75 to 203.29 kJ/kgK and 112.06 to 194.61 kJ/kgK with increase in moisture content from 10.5% to 16.87% (d.b) for both samples respectively. The observed increase in moisture content of the sample had significant effect on the specific heat values ($p < 0.05$) and this is similar with [8] ,who reported on the effect of moisture content on thermal properties of cowpea seeds and flours.

The relationship between the specific heat of the seed samples as it effected by the moisture content and temperature was expressed through the linear regression equation in Table 2 as **c** = 13.088**MC**+28.44**T**, $\mathbf{R^2}$ = 0.9879 and **c** = 13.088**MC** +28.44**T**, $\mathbf{R^2}$ = 0.9879 for Big and Small sized Horse-Eye Bean respectively.

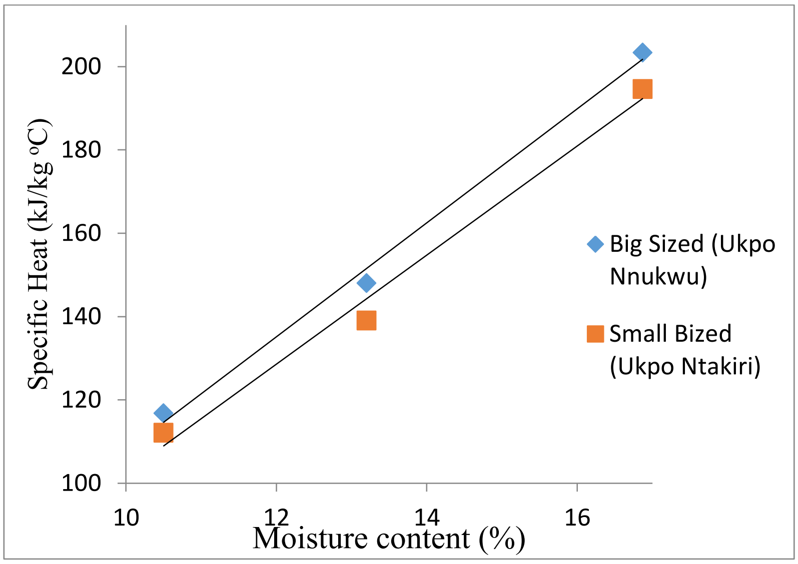

Figure 1. Effect of moisture content on the specific heat of Horse-Eye Bean seed.

The Thermal Conductivity

The thermal conductivity of both sample varieties varied with an increase in moisture content. As the moisture content increased from 10.5 to 16.87% (d.b), the thermal conductivity of the Big and Small sized Horse-Eye Bean seeds increased from 21.07 to 32.23 W/m°C and 19.85 to 24.08 W/m°C respectively (Figure 2) and this is in line with what [3] reported on moisture dependent of thermal properties of sheanut kernel. It was observed that, the mean value of the thermal conductivity measured at the three moisture content levels were significantly different at ($p < 0.05$).

The relationship between the thermal conductivity of the Horse-Eye Bean seeds with moisture content and their temperatures, was expressed through the linear regression equation as ***k*** = 2.0305**MC** + 2.4961**T**, $\mathbf{R^2}$ = 0.9716 and

k = 0.6458**MC** + 13.537**T** , $\mathbf{R^2}$ = 0.8914 for both Big and Small sized Horse-Eye Bean seed samples respectively.

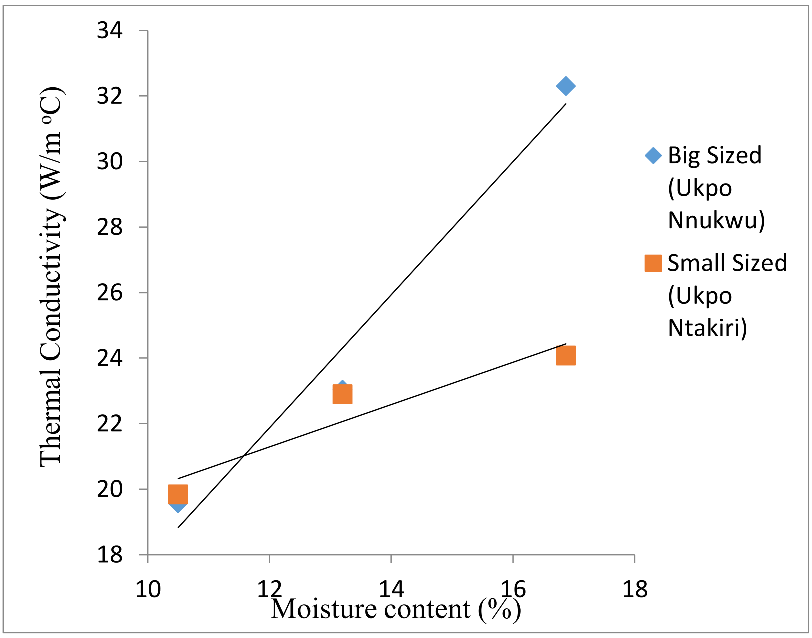

Figure 2. Effect of moisture content on the thermal conductivity of the Horse-Eye Bean seeds.

The Thermal Diffusivity

The thermal diffusivity of the Horse-Eye Bean seeds was observed to vary with change in moisture content and temperature of the sample (Table 1 and Figure 3). As the moisture content for the seed samples increased from 10.5% to 16.87% (d.b), the thermal diffusivity also increased from 3.21 x 10^{-7} to 9.19 x 10^{-7} m^2/s and 3.05 x 10^{-7} to 6.71 x 10^{-7} m^2/s for the Big and Small sized Horse-Eye Bean seeds respectively.

The increase in the moisture content of the Horse-Eye Bean seed samples had a significant effect on the thermal diffusivity mean value at ($p < 0.05$). [5], reported that similar trend on corn and wheat, while in contrary, [7], reported that increase in moisture of rice flour and seed decreased its thermal diffusivity increased. The relationship that exist among the thermal diffusivity, moisture content and temperature was best expressed through the linear regression equation as $\boldsymbol{\alpha} = 0.8712 \times 10^{-7}\,\mathbf{MC} + 5.702\mathbf{T}$, $\mathbf{R^2} = 0.98$ and $\boldsymbol{\alpha} = 0.6241 \times 10^{-7}\,\mathbf{MC} + 3.5228\mathbf{T}$, $\mathbf{R^2} = 0.9998$ for both the Big and Small sized Horse-Eye Bean seeds respectively (Table 2).

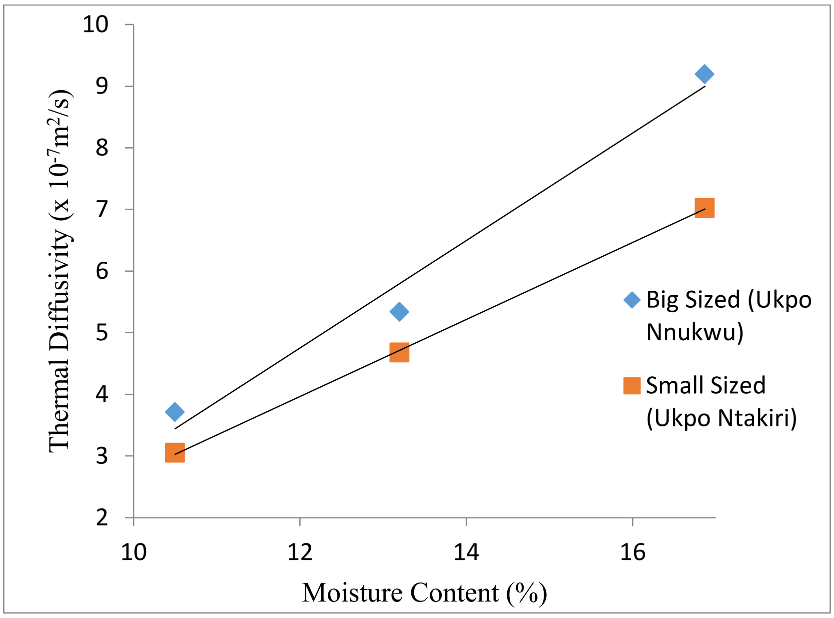

Figure 3. Effect of moisture content on thermal diffusivity of Horse-Eye Bean flour.

CONCLUSION

This study investigated thermal properties of the Horse-Eye Bean seeds as affected by moisture content and temperature and the findings revealed that;

1. The specific heat of the sample flour increased from 116.76 to 203.29 kJ/kgK and 112.06 to 194.61 kJ/kgK for both the Big and Small sized Horse-Eye Bean seeds respectively as the moisture content and temperature increases at the range of 10.5 to 16.87% (d.b) and 50 to 547^{0}C respectively. It was observed that linear relationship exists between specific heat, moisture content and temperature.
2. Thermal conductivity of Horse-Eye Bean increased from 21.07 to 32.23 W/m^{o}C and 19.85 to 24.08 W/m^{o}C for the Big and Small size Horse-Eye Bean as moisture content and temperature ranged from 10.5 to 16.87% and 50 to 547^{o}C respectively. Also, the relationship that exist between the thermal conductivity, moisture content and temperature was found to be linear.
3. Thermal diffusivity of Horse-Eye Bean increased from 3.12 x 10^{-7} to 9.19 x 10^{-7} m^2/s and from 3.05 x 10^{-7} to 6.71 x 10^{-7} m^2/s for the Big and Small sized Horse-Eye Bean seeds as the moisture content and temperature ranged from 10.5to 16.87% and 50 to 547^{0}C respectively. It was observed that thermal diffusivity of the sample and its relationship between moisture content and temperature is be described by a linear equation.

4. The thermal properties' results presented in this research work can find utilization in food industry in such processes where heat transport and storage properties of granular agricultural materials are very essential. They can be applied for instance for the conformation of drying rate, calibration of the economical drying time and determination of energetic balances of drying processes.

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UTICAJ SADRŽAJA VLAGE NA TERMIČKE PARAMETRE ZRNA KONJSKOG OKA RELEVANTNOG ZA PROCES PRERADE

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Sažetak: Specifična toplota, toplotna provodljivost i toplotna difuzivnost zrna Konjskog oka (*Mucuna sloanei*) utvrđene su u funkciji sadržaja vlage metodom koju je prikazao A. . A.C (2000). zorci koji su kori e ni bili su zrna od kulture velikog i malog Konjskog oka (*Mucuna sloanei*). Specifična toplota i toplotna provodljivost izmereni su Bomb kalorimetrom. Termička difuzivnost izračunata je iz izmerene specifične toplote, toplotne provodljivosti i zapreminske težine uzoraka. Unutar intervala sadržaja vlage od 10,5% do 16,87%, variraju vrednosti: specifične toplote, toplotne provodljivosti i toplotne difuzivnosti u zavisnosti od sadržaja vlage. Rezultati su pokazali da se navedeni parametri zrna Konjskog oka (*Mucuna sloanei*) kre u u rasponu od 116.76 do 203.29 kJ/kgK; 21.07 do 32.23 W/m^{o}C; i 3.12 x 10^{-7} do 9.19 x 10^{-7} m^2/s, za Big sized varijetet i vrednost od 112.06 do 194.61 kJ/kgK; 19.85 do 24.08 W/m^{o}C; i 3.05 x 10^{-7} do 6.71 x 10^{-7} m^2/s, za varijetet Small sized, jer se sadržaj vlage pove ava sa 10,5% na vrednost 16,87%.

Regresiona analiza je takođe urađena sa faktorima termičkih osobina sorti zrna Konjskog oka (*Mucuna sloanei*) i sadržaja vlage, i između analiziranih parametara je postojala pozitivna veza. stvareni su značajni efekti sadržaja vlage ($p < 0{,}05$) na sve istražene parametre. ala zi i dobijeni podaci stvori e pozitivan uticaj zrna Konjskog oka (*Mucuna sloanei)* u prehrambenoj industriji .

Ključne reči: *Specifična toplota, toplotna provodljivost, toplotna difuznost, brašno od zrna Konjskog oka*

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