Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XL
Broj 3, 2015.
Strane: 99 – 108

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XL
No. 3, 2015.
pp: 99 – 108

UDK: 663.534

Originalni naučni rad
Original scientific paper

PRODUCTION OF BIOETHANOL FROM POTATOES WASTES AS AN ALTERNATIVE FUEL

El-Sayed Sehsah[1*], El-Sayed Belal[2], Refai Abu Sheisha[3], Ahamed Ellawaty[1]

[1] Kafr El Sheikh University, Faculty of Agriculture,
Agricultural Engineering Department, Kafr El Sheikh, Egypt
[2] Kafr El Sheikh University, Faculty of Agriculture, Agricultural Botany Department,
Kafr El Sheikh,, Egypt
[3] Agricultural Engineering Research Institute - Dokki, Giza, Egypt

Abstract: Production of ethanol from biomass is one way to reduce both the consumption of crude oil and environmental pollution. The current research focused to produce the bioethanol from crop wastes. The study carried out in Agricultural Engineering Department and Agric. Botany Department at faculty of Agriculture, Kafrelsheikh University. The main objective in this part of the current study is producing the bioethanol from potato wastes to applicable in the engine of the farm machine. The experiment was carried out in aerobic batch digester and bioreactor after potato tubers wastes pretreatment with *Bacillus subtilis* (E34) as amylolytic bacteria for 7 days. The bioreactor system consists of three main units. The first unit was ethanol reactor which represents the main unit of the fermentation process and the second is the agitating unit required to enhance the fermentation process and to increase the efficiency of ethanol production for all treatments. Third unit is the collector tank; it is consisted of the 8 liters capacity tank with input and output valves. The output valve used to measure the pH values for different ethanol production. The 10 liters of water that was feeding in solution of potatoes wastes was heated to 30°C. Bioethanol fermentation was conducted in reactor. The yeast *Saccharomyces cerevisae* was used for fermentation process in dried form. The inoculum was used at 50 g from dried *Saccharomyces cerevisae* were used to inoculate 3 l from the pretreated potato wastes. The pH of the medium was adjusted to 4.5. All experiments were incubated at 30°C under different stirring speeds (30, 120 and 200 min^{-1}) in the reactor for 7 days. The values of the percentage of bioethanol production increased and reached to the maximum values after 18 hour of

[*] Corresponding author. E-mail: ssehsah@yahoo.de

elapsed time for 30 min^{-1}, 120 min^{-1} and 200 min^{-1} agitation rotational speeds. The maximum values of bioethanol production percentage were 37.8%, 44.45% and 68.68% after 18 hour elapsed time for 30, 120, 200 min^{-1} respectively. On the other hand, the increase of agitation speed from 30 to 200 min^{-1} tends to increase the percentage of bioethanol production. The energy requirement of volume bioethanol production increased due to increase of the agitation speed from 30 min^{-1} to 200 min^{-1}. The highest value of energy requirement was 5.9 Wh at 200 min^{-1} after 24 hours for bioethanol production. The lowest energy requirement for agitation was 8.7 Wh at 30 min^{-1} after 2 hours. Bioethanol production increased and reached to 70.9% at 18 hour of duration time for bioreactor compared to 65% bioethanol percent after 18 days for batch reactor.

***Key words**: bioethanol, production, wastes, energy*

INTRODUCTION

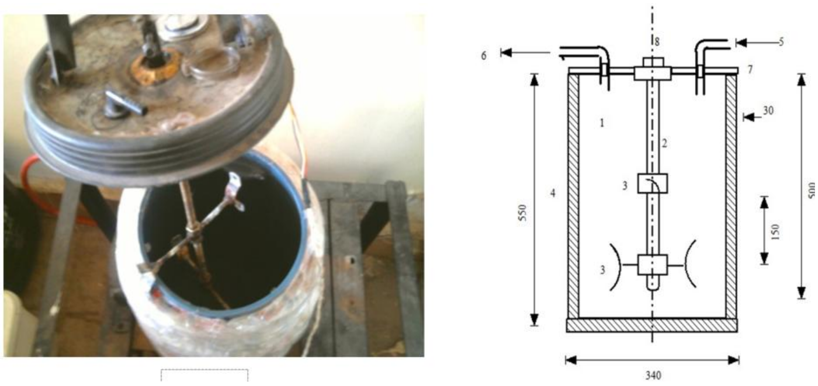
The alcohols such as methanol (CH_3OH), ethanol (C_2H_5OH), propanol (C_3H_7OH), and butanol (C_4H_9OH) can be used as alternate motor fuels. The combustion heats of alcohols are lower than those of hydrocarbons due to higher oxygen contents. Practically, any of the organic molecules of the alcohol family can be used as a fuel. However, only methanol and ethanol fuels are technically and economically suitable for internal combustion engines (ICEs) [3]. Ethanol has been used in Germany and France as early as 1894 by the then incipient industry of internal combustion engines. Brazil has utilized ethanol as a fuel since 1925. World production of biofuels is dominated by three countries or regions: the US 43%, Brazil 32% and, less so, the European Union 15% [4]. This will continue to be the case, not only because of respective government policies on biofuels addressing, to various degrees, climate change mitigation, energy security and rural development, but also because of the huge areas of productive land which are needed to provide biomass feedstocks for any significant biofuel production. [10] stated that the every bit of vegetable matter that can be fermented. There's enough alcohol in one year's yield of an acre of potatoes to drive the machinery necessary to cultivate the fields for a hundred years." However, fossil fuels were predominantly used for automobile transportation throughout the last century, obviously due to their lower production cost. As an automotive fuel, hydrous ethanol can be used as a substitute for gasoline in dedicated engines. Anhydrous ethanol, on the other hand, is an effective octane booster when mixed in blends of 5 to 30% with no engine modification requirement. [12] stated that potatoes are the second most used food in the world. Potatoes are starchy crops which do not require complex pre-treatments. [11] and [2] stated that although, it is also a high value crop, but 5 to 20% of crops that are waste potato by-products from potato cultivation could be utilized for bio-ethanol production. [20] indicated that moreover, during processing of potato, particularly in the potato chip industry, approximately 18% of the potatoes are generated as waste. Therefore, the waste from potato industry can also be utilized as growth media for the fermentation processes for the production of ethanol as it has high starch content. The wastes of potato industry are currently being utilized as animal feed. [16] stated that the starchy materials require a reaction of starch with water (hydrolysis) to break down the starch into fermentable sugars (scarification). Hydrolysis is carried out at high temperature (90 to 110°C);

however, at low temperatures, it is also possible and can contribute to energy savings. [17] showed that to convert starch into the fermentable sugars, either acid hydrolysis or enzymatic hydrolysis needs to be performed. Each has their own set of advantages and disadvantages for use. Enzyme hydrolysis is generally chosen even though high cost of enzymes and initial investment because of high conversion yield of glucose. [13] stated that however, production of ethanol from waste potato still needs to be optimized because limited research has been conducted about the utilization of potato waste for ethanol production. [6] showed that different wastes of potato industry can be a good carbon source for yeast during alcohol fermentation by studying waste from potato chips industry (98.67% total carbohydrate) and different potato cultivations (starch content in a range of 11.2% to over 19.3%), respectively. [1] stated that the biodiesel can be a good substitute as it is a renewable source and can be a partial diesel substitute to boost the farm economy; reduce uncertainty of fuel availability by efficiently using it in small portable engines in rural areas for agricultural work and make fuel availability to the farmers and self-reliant. [9] stated that bio-ethanol and bio-diesel as fuels for internal combustion engines can be produced in Hungary at a competitive price by the utilization of biomass of agricultural origin as well as chopped wood on energy plantations and baled wheat straw apt for burning for the production of heat energy. The Hungarian agriculture could provide for 10% of the domestic energy demand to be covered by these renewable energy sources. [18] showed that the ethanol produced is obtained from agricultural or agriculture-related feed-stocks. Of these, sugar-based feed-stocks account for approximately 42%, and non-sugar feed-stocks (mainly starch-based ones) for about 58% of the ethanol volume produced. [8] showed that the hydrolysis inoculated with the best combination of nutrients and fermentation was carried out at various temperatures namely 25, 30, 35 and 40°C. Ethanol content in fermented samples was estimated after 48 h of incubation. The pH of hydrolysis was adjusted to different levels and it was fermented after supplementation with the best combination of nutrients after inoculating with 10% inoculum (v/v). The fermentation was carried out at 35°C for 48 h. [7] observed that production of ethanol by *S. cerevisiae* y-1646 was favored at 35°C temperature and reached its maximum value (5.29 $g \cdot l^{-1}$) after 36 h. At 37°C, ethanol production was reduced to 4.38 $g \cdot l^{-1}$. [15] observed that maximum ethanol content of 56.8 $g \cdot l^{-1}$ was recorded after 48 h of fermentation at 30°C. However, at temperature 35, 37 and 40°C, the corresponding values were 53.6, 50.0 and 46.0 $g \cdot l^{-1}$, respectively showing a decline with increase in temperature of fermentation.

MATERIAL AND METHODS

The experimental system consists of three main units after potato tubers wastes pretreatment with *Bacillus subtilis (E34)* as amylolytic bacteria for 7 days. The first unit was ethanol reactor which represents the main unit of the fermentation process and the second is the agitating unit required to enhance the fermentation process and to increase the efficiency of ethanol production for all treatments. Third unit is the collector tank; it's consisted of the 8 l capacity tank with input and output valves. The output valve used to measure the pH values for different ethanol production. Spectorphotometer Dr. Beruno LANGE GmbH type LPG 089 was used to measure the concentration of ethanol and its specification showed as follow. Fig. 6 showed Spectorphotometer. The pH meter

KEDID Ph/ORP-6658H was used to measure the pH value during the fermentation process to obtain the proper situation of fermentation. The reactor was manufactured in the laboratory of Agricultural Engineering Department, Kafr El Sheikh University. The dimensions of reactor were 28 cm diameter and 55 cm height that correspond 6 l. The cover of the reactor was made of a circuitous stainless steel with thickness of 1 mm. The cover of the reactor equipped with a hole as the outlet of the ethanol liquid. The cover was fixed in the reactor by 5 bolts. A rubber gasket was fitted between the cover and the vessel to provide an ethanol. However the system was isolated by Wool thermal with 30 mm thickness as shown in Fig. 1.



1-reactor, 2-main rotor of the agitator, 3-blades of the agitator 4-thinks of the isolator material, 5-inlet of biomass, 6-outlet of bio-ethanol, 7-caver from plastic and steel, 8-fixed point of the electric motor, 9-dimension with mm

Figure 1. The diagram of reactor to produce the bio-ethanol

Source of microorganisms

One bacterial strain (*Bacillus subtilis* (E34) as amylolytic bacteria) was obtained from prof. Dr. Elsayed B. Belal professor of agricultural microbiology, Dep. of Agric. Botany, Fac. of Agriculture, Kafrelsheikh University and these bacterial strains was isolated in previous study as efficient starch degrading bacterial strain [5]. B. *subtilis* (E34) was cultivated in nutrient liquid medium. 250 ml nutrient liquid medium was inoculated with 2 ml of a cell suspension of *B. subtilis (E34)* (nutrient broth medium, 108 cfu·ml^{-1}) was incubated at 30°C and 150 min^{-1} for 3 days. The cultures were incubated at 30°C and 150 min^{-1} for 3 days. Thereafter, 250 ml from bacterial strain culture (108 cfu·ml^{-1}) was applied on aqueous pretreated potato wastes (1kg of crushed potato wastes: 9 liters of water for 7 days under room temperature (28°C) in reactor.

Experimental and procedures

The current study was conducted to investigate of the ability of the potatoes waste as a source of bioethanol production. The crops waste industries in Egypt are the main source of environmental pollution. The main objective in this part of the current study is producing the bioethanol from potato wastes to applicable in the engine of the farm machine. The experiment was carried out in aerobic batch digesters. The 10 liter of water that was feeding in solution of potatoes wastes was heated to 30°C. Bioethanol fermentation was conducted in reactor. The yeast S. *cerevisae* was used for fermentation process in dried form. The inoculum was used at 50 gm from dried *S. cerevisae* were used to inoculate 3 liter from the pretreated potato wastes. The pH of the medium was adjusted to 4.5. All experiments were incubated at 30°C under different stirring speeds (30, 120 and 200 min^{-1}) in the reactor for 7 days. The ethanol content was measured after 7 days fermentation [5]. The samples were collected at different elapsed time: 2, 3, 10, 18, 23 and 24 hours, to detect and determine the concentration of bioethanol by using the photometer Dr. Beruno LANGE GmbH type LPG 089. The colorimetric method was used to detect the bioethanol as follows: 1 ml of the fermented wash was taken in 500 ml pyrex distillation flask containing 30 ml of distilled water. The distillate was collected in 50 ml flask containing 25 ml of potassium dichromate solution (33.76 g of $K_2Cr_2O_7$ dissolved in 400 ml of distilled water with 325 ml of sulphuric acid and volume raised to 1 liter). About 20 ml of distillate was collected in each sample and the flasks were kept in a water bath maintained at 62.5°C for 20 min. The flasks were coaled to room temperature and the volume raised to 50 ml. 5 ml of this was diluted with 5 ml of distilled water for measuring the optical density at 600 nm using spectrophotometer [5]. A standard curve was prepared under similar set of conditions by using standard solution of ethanol containing 2 to 14% (v/v) ethanol in distilled water and then ethanol content of each sample was estimated [21]. The experiment was conducted again without the use of the enzyme where it began the process of production after 15 days and continued until 30 days.

RESULTS AND DISCUSSION

The result focused on the bioethanol production from the crop waste specially the potatoes waste. Regarding to adding bacteria to activate the fermentation process in bioreactor, as well as reducing the time required for ethanol production (fermentation time or elapsed time). The result indicated that the highest values of ethanol production were obtained after eighteenth day's elapsed fermentation time in batch reactor. The ethanol production from batch reactor was produced without any edition of engineering treatment such as the agitation process under laboratory conditions. The increasing of fermentation time or elapsed time tends to increase the ethanol production. The fermentation time was 18 days that produced the maximum ethanol percentage values. On the other hand the production of ethanol after 18 days goes to decrease. This result may be due to decrease glucose that converts to ethanol as shown in Fig. 2. It noticed that production of the bioethanol process started after two hours from elapsed time with agitated at different rotational speed 120 min^{-1} and 200 min^{-1} as shown in Fig. 3. The values of the percentage of bioethanol production increased and reached to the maximum values after 18 hour of elapsed time for 30 min^{-1}, 120 min^{-1} and 200 min^{-1} agitation rotational speeds. The maximum values of bioethanol production percentage were 37.8%, 44.45% and 68.68% after 18 hours elapsed time for 30, 120, 200 min^{-1}, respectively. On the other hand, the increase of agitation speed from 30 to 200 min^{-1} tends to increase the percentage of Bio-ethanol production. The above result may be due to the effect of agitation system in bioreactor that tends to improve the distribution of the microorganisms during the fermentation process. During the 18 hours fermentation time, the bioethanol percent increased by increasing the duration time. On the other hand, after 18 hours of fermentation time the bio-ethanol percent tends to decreased. This result may be due to the toxic effect of ethanol on S. *cervesiae*. It could be recommended that the starch of potatoes most be feeding in the bioreactor to obtain the continually bioethanol production after 18 hours of fermentation time.

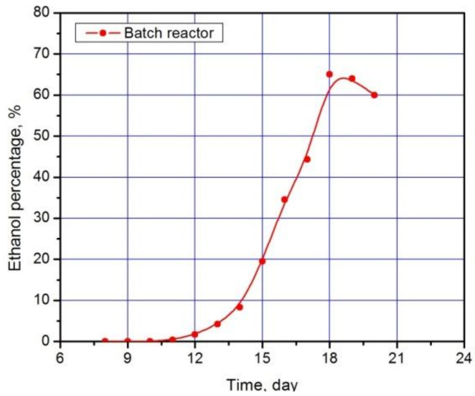


Figure 2. Effect of the fermentation time on ethanol production from batch reactor

Energy requirement for ethanol production

Fig. 4 presents that the effect of rotational speed for agitation system and operation duration time on the energy requirement for bioethanol production. It is clearly that, the energy requirement of volume bioethanol production increased due to increase of the agitation speed from 30 min^{-1} to 200 min^{-1} The highest value of energy requirement was 5.9 Wh at 200 min^{-1} after 24 hours for 10 letter media to produce bioethanol . The lowest energy requirement for agitation was 8.7 Wh at 30 min^{-1} after 2 hours. Theoretically, it could be calculated the maximum energy requirement for agitation to produce one ton of bioethanol, it may be about 0.84 $kWh \cdot t^{-1}$. Also, the energy requirement for heating one liter of water was 0.16 Wh. The energy requirement for pretreatment of waste potatoes was 0.3 $kWh \cdot kg^{-1}$. As well as the total energy to produce one ton of bioethanol under laboratory conditions may be around 1 kWh.

Comparison between bioreactor and batch reactor

Fig. 5 displays the ethanol percentage from bioreactor and batch reactor. It's clearly that Bio-ethanol production increased and reached to 70.9% at 18 hour of fermentation time for bioreactor compared to 65% bioethanol percent at 18 days for batch reactor. The bioreactor with agitation system and controlled temperature may be tends to produce the high values of ethanol production in short time compared the batch reactor. The highest values of the volume ethanol production increased due to increase the rotational speed of the agitation system. The highest percentage production of ethanol was 71% at speed of 200 min^{-1} for bioreactor.

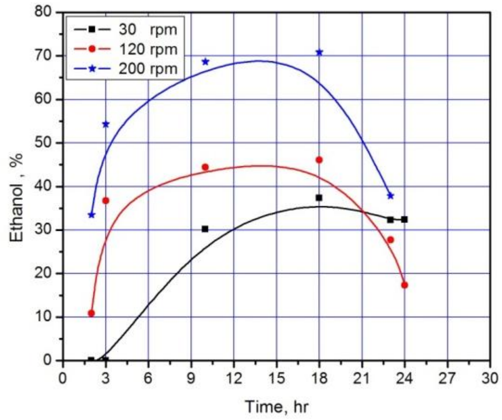


Figure 3. Effect of rotational speed of the agitation system and duration time on the ethanol percentage production

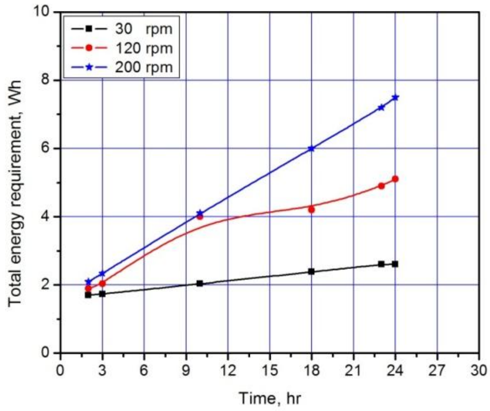


Figure 4. Effect of agitator rotational speed of motor and operation time on the energy requirement

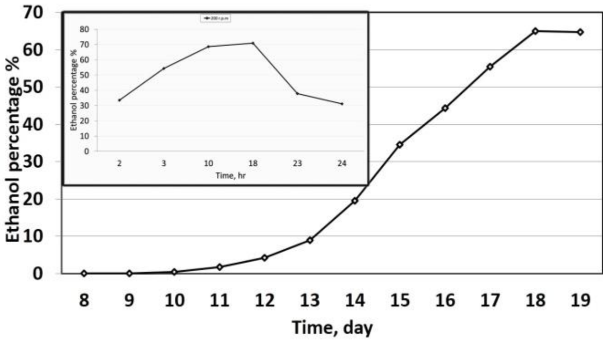


Figure 5. Ethanol percentage production from bioreactor and batch reactor

By comparing the elapsed fermentation time the bioreactor goes to reduce the elapsed time compared to the batch reactor. It noticed that the production of the bioethanol process from bioreactor started after two hours but the production of the ethanol process from batch reactor started after eleven days as shown in Fig. 5.

CONCLUSIONS

It could be summarized that the Bacilace E34 with agitated the potatoes starch tends to increase the ethanol production and reduce the fermentation time into the reactor. The above results may be due to the agitation made a good distribution of the E34 in the starch of potatoes. It's clearly that Bio-ethanol production increased and reached to 70.9% at 18 hour of fermentation time for bioreactor compared to 65% bioethanol percent at 18 days for batch reactor. The increasing of rotational speed tends to increase energy requirement to produce the bioethanol.

BIBLIOGRAPHY

[1] Abhinab, M., Ghanshyam, T., Abhay, K., Sudhakar, J., Jindal, S. 2014. Suitability of rice brain oil as feedstock for biodiesel making. *Agricultural Engineering*, Vol. XXXV. No. 1, 2014. pp: 15 – 20.

[2] Adarsha, R., Asha, D.L., Balaji, R.R. 2010. Production of bio-ethanol from Pectobacterium carotovorum induced soft rotten potatoes. *Afr. J. Microbiol. Res.* 4(12): 1340-1342.

[3] Bala, B.K. 2005. Studies on biodiesels from transformation of vegetable oils for diesel engines. *Energy Edu. Sci. Technol*. 15:1–43.

[4] Baylis, A.D. 2008. Biofuels: what impact on crop protection and seeds now? Part 1: Current status of biofuels and crop feed-stocks. *Outlooks on Pest Management,* 19(5), 217-9.

[5] Belal, E.B. 2013. Bioethanol production from rice straw residues. *Brazilian Journal of Microbiology* 44, 1, 225-234.

[6] Fadel, M. 2000. Alcohol production from potato industry starchy waste. *Egyptian J. Microbiol*. 35(3): 273-287.

[7] Hashem, M., Darwish, S.M.I. 2010. Production of bioethanol and associated by-products from potato starch residue stream by *Saccharomyces cerevisiae*. *Biomass Bioenergy,* 34: 953–959.

[8] Joginder, S.D., Ashok, K., Sunil, K.T. 2013. Bioethanol production from starchy part of tuberous plant (potato) using *Saccharomyces cerevisiae* MTCC-170. *Academic Journals* Vol. 7(46), pp. 5253-5260.

[9] Magó, L., Topisirovic, G., Oljača, S., Oljača, V.M. 2010. Solid biomass potential from agriculture in Hungary and Serbia. *Agricultural Engineering*, Vol. XXXV, No. 4. p.p. 35-45.

[10] Licht, F.O. 2006. *World Ethanol Market: The Outlook to 2015*, Tunbridge Wells, Agra Europe Special Report, UK.

[11] Limatainen, H., Kuokkanen, T., Kaariainen, J. 2004. Development of bio-ethanol production from waste potatoes. In: Pongracz E (ed.) *Proceedings of the Waste Minimization and Resources Use Optimization Conference.* University of Oulu, Finland. Oulu University Press: Oulu. pp 123-129.

[12] Minal, D., Deshpande, R.S. 2010. Bio-fuel from cellulosic agricultural waste. *Intl. J. Chem. Eng. Res*. 2(2): 197-217.

[13] Pandey, A., Nigam, P., Soccol, C.R., Soccol, V.T., Singh, D., Mohan, R. 2000. Advances in microbial amylases. *Biotechnol. Appl. Biochem.* 31:135– 152.

[14] Rani, P., Garg, F.C., Sharma, S.S., Wati, L. 2009. Ethanol production from potato starch. *Ind. Food Packer.* 63(4), 63-68

[15] Rani, P., Sharma, S., Garg, F.C., Kushal, R., Leela, W. 2010. Ethanol production from potato flour by Saccharomyces cerevisiae. *Indian J. Sci. Technol.* 3(7): 733-736.

[16] Sanchez, O.J., Carlos, A.C. 2008. Trends in biotechnological production of fuel ethanol from different feedstock. *Biores. Technol.* 99(13): 5270-5295.

[17] Tasic, M.B., Konstantinovic, B.V., Lazic, M.L., Veljkovic, V.B. 2009. The acid hydrolysis of potato tuber mash in bioethanol production. *Biochem. Eng. J*. 43: 208–211.

[18] Tolmasquim, M.T. 2007. *Bioenergy for the future.* In: Conference on Biofuels: an option for a less carbonintensive economy [cited 14 April 2008]. Available through: http://www.unctad.org/sections/wcmu/docs/uxii_ditc_tedb_ 013_en.pdf. [Accessed date: 31.12.2014.]

[19] Turhan, I., Bialka, K.L., Demirci, A., Karhan, M. 2010. Ethanol production from carob extract by using *Saccharomyces cerevisiae*. *Biores. Technol.* 101(11): 5290–5296.

[20] Yamada, S., Shinomiya, N., Ohba, K., Sekikawa, M., Oda, Y. 2009. Enzymatic hydrolysis and ethanol fermentation of by-products from potato processing plant. *Food Sci. Technol.* Res. 15(6): 653-658.

[21] Yoswathana, N., Phuriphipat, P. 2010. Bioethanol Production from Rice Straw. *Ene Rese J* 1:26-31.

PROIZVODNJA BIOETANOLA KAO ALTERNATIVNOG GORIVA IZ OSTATAKA KROMPIRA

El-Sayed Sehsah[1], El-Sayed Belal[2], Refai Abu Sheisha[3], Ahamed Ellawaty[1]

[1]Univerzitet Kafr El Sheikh, Poljoprivredni fakultet, Institut za poljoprivrednu tehniku, Kafr El Sheikh, Egipat
[2] Univerzitet Kafr El Sheikh, Poljoprivredni fakultet, Institut za poljoprivrednu botaniku, Kafr El Sheikh,, Egipat
[3] Istraživački institut za poljoprivrednu tehniku - Dokki, Giza, Egipat

Sažetak: Proizvodnja etanola iz biomase je jedan od načina za smanjenje potrošnje sirove nafte i zagađenja okoline. Skorija istražuvanja se odnose na proizvodnju bioetanola iz biljnih ostataka. Ova studija je izvedena na Institutima za poljoprivrednu tehniku i poljoprivrednu botaniku Poljoprivrednog fakulteta Univerziteta Kafrelsheikh. Osnovni cilj ovog dela istraživanja je proizvodnja bioetanola iz ostataka krompira, koji će moći da se koristi u motorima poljoprivrednih mašina. Ogled je izveden u aerobnom digestoru i bioreaktoru posle prethodnog tretmana ostataka krompira amilolitičkom bakterijom *Bacillus subtilis* (E34) u trajanju od 7 dana. Sistem bioreaktora sastoji se od tri glavne jedinice. Prva je etanolski reaktor, u kome se odvija glavni deo procesa fermentacije. Drugi je aktivaciona jedinica koja pojačava fermentaciju i povećava efikasnost produkcije etanola u svim tretmanima. Treća jedinica je kolektorski rezervoar; on se sastoji od tanka kapaciteta 8 litara sa ulaznim i izlaznim ventilima. Izlazni ventil ujedno i meri pH vrednosti proizcedenog etanola. 10 litara vode, koja se dodaje u rastvor ostataka krompira, je zagrevano na 30°C. Fermentacija bioetanola je izvođena u reaktoru. Za fermentaciju je korišćen suvi kvasac, glivica soja *Saccharomyces cerevisae*. 50 g suvog *Saccharomyces cerevisae* je upotrebljeno za inokulaciju 3 litra prethodno tretiranog otpada krompira. pH vrednost je bila podešena na 4.5. U svim ogledima, inkubacija je na 30°C, pod različitim brzinama podsticanja (30, 120 i 200 min^{-1}) u reaktoru trajala 7 dana. Procentualne vrednosti produkcije bioetanola rasle su dostigle maksimume posle 18 časova pri aktivacionim brzinama rotacije od 30 min^{-1}, 120 min^{-1} i 200 min^{-1}. Maksimalne procentualne vrednosti produkcije bioetanola iznosile su 37.8%, 44.45% i 68.68% posle 18 časova, pri aktivacionim brzinama rotacije od 30, 120, 200 min^{-1}, redom. Sa druge strane, povećanje aktivacione brzine sa 30 na 200 min^{-1} ima tendenciju povećanja procenta produkcije bioetanola. Zahtevi za energijom pri proizvodnji veće zapremine bioetanola su se povećali zbog povećanja aktivacione brzine sa 30 min^{-1} na 200 min^{-1}. Najveća potrošnja energije bila je 5.9 Wh pri 200 min^{-1} posle 24 časa proizvodnje etanola. Najmanja potrošnja energije za aktivaciju bila je 8.7 Wh pri 30 min^{-1} posle 2 časa. Produkcija bioetanola porasla je i dostigla 70.9% posle 18 časova u bioreaktoru, u poređenju sa 65% bioetanola posle 18 dana u digestoru.

***Ključne reči**: bioetanol, proizvodnja, otpad, energija*

Prijavljen: *Submitted*:	31.12.2014.
Ispravljen: *Revised*:	06.07.2015.
Prihvaćen: *Accepted*:	21.08.2015.