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USING MISCANTHUS RAW MATERIAL FOR SOLID BIOFUEL PRODUCTION

Nowadays, the most relevant issue for Ukraine is the search for non-traditional renewable energy sources, among which energy crops deserve special attention, as they are the main carbon dioxide absorbent and provide high yields of biomass, which could be used for energy purposes, for biofuel production. Energy crops are plants that are specially cultivated to be used as a fuel or for biofuel production. Plant by-products (straw, sunflower husks, corn stalks, etc.) and specially cultivated plants – miscanthus, switchgrass (thatch grass), willow, and poplar – can be the sources of energy feedstock.

The tendency of rising prices of traditional fuels gives impetus to the use of solid fuel combustion appliances burning biomass not only in the private sector, but also in the municipal heat supply facilities. When choosing the type of solid biomass, its value and availability in the region as well as the technologies and equipment for its combustion should be taken into account.

This paper represents the experimental findings of miscanthus filtration drying. The main technical characteristics (bulk density, porosity, equivalent diameter) of chipped miscanthus are provided. The dependence of the drying rate of chipped miscanthus on its moisture content is shown. The dependence of filtration drying on the technological parameters of heat agent and material layer height is analyzed. The authors show that the filtration drying rate during full saturation of the heat agent with moisture vapour does not depend on the height of chipped miscanthus layer.

Key words: dynamics, miscanthus, rate of filtration drying, stationary layer.

Problem statement. The development and use of renewable energy sources, in particular plants biomass, is essential in reducing Ukraine’s energy dependence [3]. In recent decades, the increasing demand for renewable energy has led to the increased interest in energy crops. Ukraine has great potential of available biomass and good preconditions for expanding its use in fuel production [3].

At present, *Miscanthus giganteus* biomass production ranks fourth in the world in terms of biomass production. Its share in the total primary energy production reaches 10% [3]. In the production of biofuels, perennial crops have significant advantages over traditional ones: high biomass productivity, positive energy balance, unpretentious soil, drought resistance. Therefore, these plants can be grown in low-yielding soils unsuitable for the cultivation of food crops [4]. The authors [3] found that *Miscanthus giganteus* L., *Silphium perfoliatum* L., *Polygonum sachalinense* L., *Polygonum wyrichii* L., *Sida hermaphrodita* L., *Helianthus tuberosus* L., and *Heliánthus ánnuus* L. are the most productive among perennial crops.

Agastache foeniculum L. and *Hyssopus officinalis* L., which are oil crops, are the least productive. In particular, *Miscanthus giganteus* L. provides 12.0 t/ha of dry weight, 210 GJ/ha and 7.2 t/ha of conventional fuel. In recent years, *Miscanthus giganteus* has been cultivated in Ukraine with the aim of investigating the possibility of its industrial use in biofuel production [4]. It is known that *Miscanthus giganteus* is the most productive and energy-efficient in the natural conditions of Ukraine. It can be used in many different ways: as an alternative energy source, as a building material, in animal husbandry, as bedding and animal feedstuff, etc.

Energy analysis of the main stages of biofuel production allows identifying the main areas that affect energy efficiency and production cost. Thermal drying is the most energy-intensive process in the production of biofuels. About 90% of thermal energy is spent on moisture evaporation. On average, this process consumes 12–20% of the biofuel product produced at the enterprise [5].

Biomass is by far the fourth largest fuel resource in the world and produces about 1.25 million tonnes of fuel per year, which accounts for 15% of all primary energy, and in some countries this figure exceeds 30%. According to the program “Energy Strategy of Ukraine for the Period until 2030”, biomass share in the fuel and energy system is estimated at 7.8% (6.3 million tonnes) in 2020 [6]. As an object of drying, solid biofuel has a complex natural structure due to its primary origin, physical condition, etc. Therefore, it is necessary to consider these factors in the process of convective drying that is most widely used for biomass processing (mainly up to 70%), in drum- and conveyor-type dryers [6].

As the crop is unpretentious to soil conditions, it is recommended to grow miscanthus in marginal or unproductive lands. There are from 3 to 5 million hectares of such lands in Ukraine, which have been removed from cultivation due to their low fertility, susceptibility to erosion processes, etc. Growing perennial crops in these lands for biofuel production will protect the humus layer from erosion and improve the country's environmental and energy situation.

Miscanthus should be fertilized about every 5 years to improve its growth processes during the growing season.

Miscanthus yield in Ukraine depends directly on the climatic and soil conditions of its cultivation. It is best suited for medium-density soils. Due to the branched root system, it can be grown in sandy soils. Miscanthus is well-adapted to unfavorable growing conditions, in particular to the high content of salts in the soil. Another amazing property of the plant is that *Miscanthus giganteus* can absorb heavy metals from the soil.

Literature review. *Miscanthus giganteus* has been known for a long time on three continents – in Asia, Africa and Australia. It appeared in Europe in the early 1900s and gained popularity only a century ago when energy dependence became a very serious issue. At that time, the plant was recognized as a revolutionary crop in agriculture, as a biofuel feedstock and raw material for energy production by means of direct combustion. At present, *Miscanthus giganteus* is grown and processed for sale in the form of pellets or briquettes in many European countries: Austria, Denmark, France, Germany, Hungary, Poland, Sweden, United Kingdom and others. Moreover, the cultivation area of this crop is constantly increasing.

Experts from the National Bioenergy Union, who have studied *Miscanthus giganteus*, say that if 10% of Europe's fields are planted with this wonderful plant, up to 91% of electricity can be saved. By the way, the EU's Common Agricultural Policy obliges the farmers owning more than 15 hectares of land to allocate at least 5% of the area – buffer strips, landscape areas, arable land and others – to grow perennial energy crops without using pesticides and chemical fertilizers or with their minimum use.

In Ukraine, this plant is not grown on a large scale, only its small cultivation areas appear from time to time in some regions. Thus, in 2007, an experiment on miscanthus cultivation began in Zhytomyr and Kharkiv oblasts.

Miscanthus giganteus is propagated by the so-called rhizome, a part of the underground stem that contains the buds and can be used for vegetative propagation by division. This is one of the most time-consuming parts in miscanthus cultivation technology. Typically, rhizomes are taken from one- or two-year-old miscanthus plants. The clumps of miscanthus are usually dug in spring. During wintering, the clumps of miscanthus can be damaged by low temperatures. Such rhizomes are not suitable for planting. In the Ukrainian climate, miscanthus begins to sprout in April, when the soil temperature reaches 10 ... 12°C at a depth of 10 cm, and stops growing with the onset of frosts in October–November. Late spring frosts are dangerous to plants, as they cause shoots dying and reduce the total crop growing period. The plant is the most vulnerable during the first wintering – in the first year of planting rhizomes. Under favorable natural conditions, the perennial miscanthus can reach the height of up to 4 m or more, and the diameter of the stems reaches 2 cm.

In the Ukrainian realities, *Miscanthus giganteus* grows quite well and can withstand frosts up to –25°C with sufficient snow cover. Since *Miscanthus giganteus* is a perennial crop that can grow in one place for up to 20–25 years, soil preparation and planting rhizomes are among the most important elements in its growing process.

During the growing season, miscanthus requires about 700 mm of precipitation. Its demand for water is much higher than the average annual precipitation in Ukraine. Such extensive needs for water despite its low consumption (about 250 l) for producing 1 kg of dry weight can be explained by a large biomass yield per unit area.

The authors [6] discovered that the method of partial waste heat recovery (recirculation) was better and more efficient (by 18–26%). In the recirculation dryer, the amount of circulating air increased by 1.3–1.9 times.

In the article [7], the drying process of straw biofuel was investigated. It was established that when making briquettes from straw with high moisture content it was advisable to dry them in two stages. At the first stage, fuel briquettes were dried with atmospheric air, at the second – the air after the first stage was heated by a heater, which provided more efficient drying.

In the work [8] the kinetics of drying chips as a raw material for producing fuel briquettes was investigated. The optimum drying temperatures of the material with different fractional composition were obtained, the dependence of the raw material moisture on drying time and the influence of fractional composition on the drying process were studied. The characteristics of the drying equipment, optimal for the production technology of fuel briquettes, were established.

Methods and materials. The purpose of this paper is a theoretical and experimental study of the filtration drying dynamics of chipped miscanthus, which is a perennial rhizome plant used to produce solid biofuels.

To assess the basic parameters of the studied material, the main technical characteristics of chipped miscanthus are shown in Table 1.

Table 1

Main technical characteristics of chipped *Miscanthus giganteus L.*

ρ, kg/m^3	ρ_{ef}, kg/m^3	ε_p, m^3/m^3	d_e, 10^3 m	a, m^2/m^3
122.23	562	73.75	4.18	705

The bulk density (ρ) of chipped miscanthus was determined according to the standard procedure provided by GOST 10840, the total porosity of the investigated materials (ε_p) was defined by the picnometer method. The equivalent diameter of the channels (d_e), through which the heat agent is filtered, was determined by the dependence:

$$d_e = \frac{4 \cdot \varepsilon_p}{a}, \tag{1}$$

where a is the specific surface area of the chipped miscanthus layer determined by the PMC-500 device according to the method described in [8].

Drying kinetics describes the change in the material's moisture over time depending on the dried material properties and determines the drying time and energy consumption. Therefore, experimental studies of the filtration drying kinetics of chipped miscanthus were performed according to the methods described in the articles [8-10].

Results and discussion. Figure 1 shows the dependence of the drying rate of chipped miscanthus on its moisture content. Point *b* corresponds to the end of the full saturation period of the heat agent with moisture vapour, i.e. mass transfer front of the perforated plate and transition from the filtration drying process to the partial saturation of the heat agent.

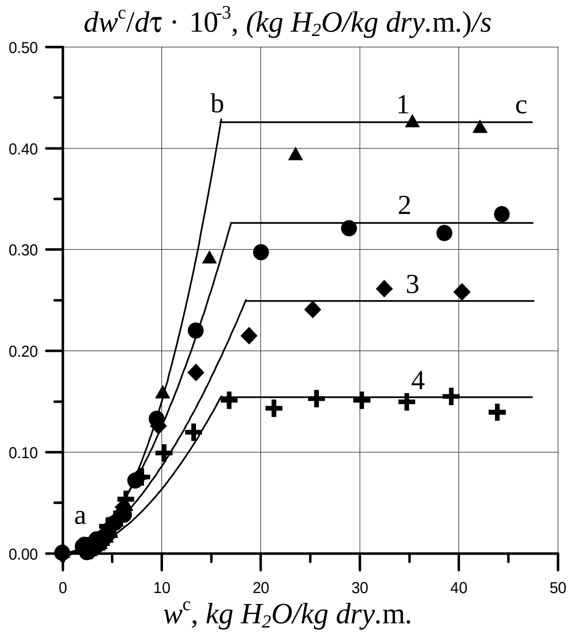

Fig 1. Filtration drying rate of chipped miscanthus at different filtration rates of the heat agent
(H = 60 mm, t = 60°C), 1 – ω = 0.68 msc; 2 – ω = 1.14 m/s; 3 – ω = 1.6 m/s; 4 – ω = 2.05 m/s

Due to the fact that the filtration rate of the heat agent varies from ω_0 = 0.68 m/s to ω_0 = 2.05 m/s, the drying rate increases from $dw^c/d\tau$= 0.002·10^{-3} (kg H_2O/kg dry.m)/s to $dw^c/d\tau$ = 0.0047·10^{-3} (kg H_2O/kg dry.m)/s, which is explained by the increase in heat and mass transfer coefficients. This also applies to Figure 2 in the case when the heat agent temperature rises and, as a consequence, the drying potential of the heat agent rises, which leads to the drying rate increase.

The analysis of Figure 2 shows that the drying rate increases when the layer height decreases. This is explained by the fact that the moisture content change of the layer was determined by the weight method based on the dry material weight.

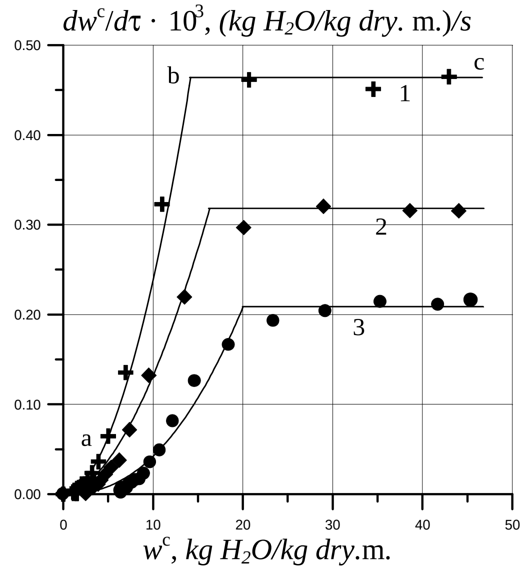

Fig 2. Filtration drying rate of chipped miscanthus at different heat agent temperatures
(H = 60 mm, ω_o = 1,6 m/s), 1 – t = 40°C; 2 – t = 60°C; 3 – t = 80°C

It is evident that as the height increases, the moisture content in the layer and the mass of dry material increase too. In Figure 3, the drying rate during full saturation of the heat agent is the highest for the smallest layer height.

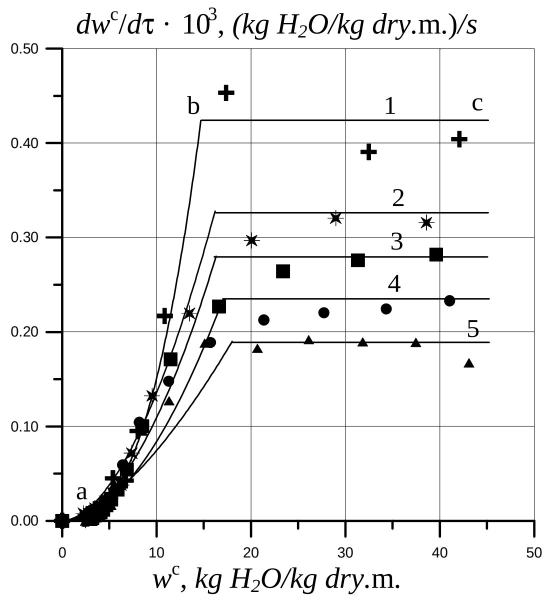

Fig 3. Filtration drying rate of chipped miscanthus at different layer heights (*ω_o = 1,6 m/s, t = 60°C*)

However, as shown above (Fig. 2), the drying rate during full saturation of the heat agent with moisture vapour does not depend on the layer height, which can be explained by the stability of drying potential at the same temperature and filtration rate of the heat agent (the amount of moisture removed per unit of time is a constant).

Conclusions. The dynamics of filtration drying of chipped miscanthus was investigated. The existence of two stages in the filtration drying of chipped miscanthus was substantiated. The dependence of filtration drying on the technological parameters of heat agent (drying potential) and the material layer height were analyzed. It was proved that the filtration drying rate does not depend on the material layer height during full saturation of the heat agent with moisture vapour.

References

1 Suchasnyi stan ta perspektyvy rozvytku bioenerhetyky v Ukraini / [Heletukha H.H., Zheliezna T.A., Kucheruk P.P., Oliinyk Ye.M.] // Analitychna zapyska BAU №9. – Bioenerhetychna asotsiatsiia Ukrainy, 2014. – 32 s. – Rezhym dostupu: http://uabio.org/img/files/docs/position-paper-uabio-9-ua.pdf

2 Enerhetychni roslyny yak alternatyva tradytsiinym vydam palyva / [Khivrych O. B., Kvak V. M., Kaskiv V. V. ta in.] // Ahrobiolohiia. – 2011. – Vyp. 6. – S. 153–157.

3 Roik M.V. Perspektyvy vyroshchuvannia enerhetychnoi verby dlia vyrobnytstva tverdoho biopalyva / Roik M.V., Humentyk M. Ya., Mamaisur V. V. // Bioenerhetyka. – 2013. – № 2. – S. 18–19.

4 Ivakhiv V. Enerhetychna verba yak rishennia dlia malykh mist Ukrainy [Elektronnyi resurs] / V. Ivakhiv / – Rezhym dostupu: http://ua- energy.org/post/27476.

5 Kurhak V. H. Enerhetychna tsinnist bahatorichnykh travianykh fitotsenoziv / V. H. Kurhak, H. V. Yefremova, Yu. V. Leshchenko, A. M. Tkachenko // Zbirnyk naukovykh prats Natsionalnoho naukovoho tsentru "Instytut zemlerobstva NAAN". - 2015. - Vyp. 2. - S. 164-173.

6 Stefanovska T. R. Struktura entomokompleksu miskantusu hihantskoho Miscanthus Giganteus [Elektronnyi resurs] / T. R. Stefanovska // "Naukovi dopovidi NUBiP Ukrainy". – 2012. – Rezhym dostupu do resursu: http://nd.nubip.edu.ua/2012_4/12str.pdf.

7 Sniezhkin Yu. F. Enerhetychnyi analiz tekhnolohii vyrobnytstva tverdoho biopalyva / Yu. F. Sniezhkin, D. M. Korinchuk, M. M. Bezhin, I. V. Stepchuk // Naukovi pratsi [Odeskoi natsionalnoi akademii kharchovykh tekhnolohiy]. – 2014. – Vyp. 45(3). – S. 187-190.

8 Dubrovin V. Metody ta rezultaty teoretychnykh doslidzhen sushinnia syrovyny dlia tverdykh biopalyv / V. Dubrovin, O. Yeremenko, S. Vyhovskyi, M. Dakhno // Tekhniko-tekhnolohichni aspekty rozvytku ta vyprobuvannia novoi tekhniky i tekhnolohii dlia silskoho hospodarstva Ukrainy. – 2013. – Vyp. 17(2). – S. 255-266. – Rezhym dostupu: http://nbuv.gov.ua/UJRN/Ttar_2013_17%282%29__35

9 Semirnenko Yu. I. Udoskonalennia protsesu sushky palyvnykh bryketiv iz solomy / Yu. I. Semirnenko // Visnyk Sumskoho natsionalnoho ahrarnoho universytetu. Seriia : Mekhanizatsiia ta avtomatyzatsiia vyrobnychykh protsesiv. – 2015. – Vyp. 11. – S. 72-75. – Rezhym dostupu: http://nbuv.gov.ua/UJRN/Vsna_mekh_2015_11_17

10 Issledovanie kinetiki sushki opilok i struzhki v intensivnom rezhime / I. A. Telnov [i dr.] // Vestnik Nats. tekhn. un-ta "KhPI" : sb. nauch. tr. Temat. vyp. : Innovatsionnye issledovaniya v nauchnykh rabotakh studentov. – Kharkov : NTU "KhPI". – 2012. – № 10. – S. 139-144.

11Atamaniuk V.M. Kinetyka filtratsiinoho sushinnia shlaku teplovykh elektrostantsii [Tekst] / V.M. Atamaniuk, I.R. Barna // Zbirnyk naukovykh prats ONAKhT. – Odesa. – 2012, – T.2, Vyp.41, – S. 89-93.

12 Mosiuk M. I. Hidrodynamika i teplomasoobmin pid chas sushinnia podribnenoi “enerhetychnoi” verby v statsionarnomu shari [Tekst]: Avtoref. dys...kand. tekhn. nauk: 05.17.08. / M. I. Mosiuk; [NU Lvivska politekhnika]. – Lviv, 2012. – 22 s.

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ВИКОРИСТАННЯ РОСЛИННОЇ СИРОВИНИ МІСКАНТУСА ДЛЯ ВИРОБНИЦТВА ТВЕРДОГО БІОПАЛИВА

Найактуальнішим сьогодні для України є пошук нетрадиційних відновлювальних джерел енергії, серед яких на особливу увагу заслуговують енергетичні рослини, які є головним абсорбентом вуглекислого газу, утворюють високі врожаї біомаси, яку можна було б використати на енергетичні цілі для виробництва біопалива. Енергетичні культури – це рослини, які спеціально вирощуються для використання безпосередньо як паливо або для виробництва біопалива [1]. Джерелом енергетичної сировини можуть бути як побічні продукти рослинного походження (солома, соняшникове лушпиння, стебла кукурудзи тощо), так і спеціально призначені для цього рослини – міскантус, світчграс (лозоподібне просо), верба, тополя [2].

Тенденція здорожчання традиційних видів палива дає поштовх до використання твердопаливних котлів на біомасі не тільки у приватному секторі, але і в комунальному теплопостачаючому господарстві. При виборі форми твердої біомаси потрібно враховувати її вартість та доступність в регіоні, а також від технічно доступні рішення та обладнання для її спалювання.

У цій статті представлено результати експериментальних досліджень динаміки фільтраційного сушіння подрібненого міскантуса. Наведено основні технічні характеристики (насипна густина, пористість, еквівалентний діаметр) подрібненого міскантуса. Показана залежність швидкості сушіння подрібненого міскантуса залежно від її вологості та проаналізовано залежність фільтраційного сушіння від технологічних параметрів теплового агенту і висоти шару матеріалу. Показано, що швидкість фільтраційного сушіння в період повного насичення теплового агента парами вологи не залежить від висоти шару подрібненого міскантуса.

Ключові слова: динаміка, міскантус, швидкість фільтраційного сушіння, стаціонарний шар.

Література

1 Сучасний стан та перспективи розвитку біоенергетики в Україні / [Гелетуха Г.Г., Желєзна Т.А., Кучерук П.П., Олійник Є.М.] // Аналітична записка БАУ №9. – Біоенергетична асоціація України, 2014. – 32 с. – Режим доступу: http://uabio.org/img/files/docs/position-paper-uabio-9-ua.pdf

2 Енергетичні рослини як альтернатива традиційним видам палива / [Хіврич О. Б., Квак В. М., Каськів В. В. та ін.] // Агробіологія. – 2011. – Вип. 6. – С. 153–157. 3. Роїк М.В. Перспективи вирощування енергетичної верби для виробництва твердого біопалива / Роїк М.В., Гументик М.Я., Мамайсур В.В. // Біоенергетика. – 2013. – № 2. – С. 18–19. 4. Івахів В. Енергетична верба як рішення для малих міст України [Електронний ресурс] / В. Івахів / – Режим доступу: http://ua- energy.org/post/27476.

3 Кургак В. Г., Енергетична цінність багаторічних трав’яних фітоценозів / В. Г. Кургак, Г. В. Єфремова, Ю. В. Лещенко, А. М. Ткаченко // Збірник наукових праць Національного наукового центру "Інститут землеробства НААН". - 2015. - Вип. 2. - С. 164-173.

4 Стефановська Т. Р. Структура ентомокомплексу міскантусу гігантського Miscanthus Giganteus [Електронний ресурс] / Т. Р. Стефановська // "Наукові доповіді НУБіП України". – 2012. – Режим доступу до ресурсу: http://nd.nubip.edu.ua/2012_4/12str.pdf.

5 Снєжкін Ю. Ф. Енергетичний аналіз технологій виробництва твердого біопалива / Ю. Ф. Снєжкін, Д. М. Корінчук, М. М. Безгін, І. В. Степчук // Наукові праці [Одеської національної академії харчових технологій]. - 2014. - Вип. 45(3). - С. 187-190.

6 Дубровін В., Методи та результати теоретичних досліджень сушіння сировини для твердих біопалив / В. Дубровін, О. Єременко, С. Виговський, М. Дахно // Техніко-технологічні аспекти розвитку та випробування нової техніки і технологій для сільського господарства України. - 2013. - Вип. 17(2). - С. 255-266. - Режим доступу: http://nbuv.gov.ua/UJRN/Ttar_2013_17%282%29__35

7 Семірненко Ю. І., Удосконалення процесу сушки паливних брикетів із соломи / Ю. І. Семірненко // Вісник Сумського національного аграрного університету. Серія : Механізація та автоматизація виробничих процесів. - 2015. - Вип. 11. - С. 72-75. - Режим доступу: http://nbuv.gov.ua/UJRN/Vsna_mekh_2015_11_17

8 Исследование кинетики сушки опилок и стружки в интенсивном режиме / И. А. Тельнов [и др.] // Вестник Нац. техн. ун-та "ХПИ" : сб. науч. тр. Темат. вып. : Инновационные исследования в научных работах студентов. – Харьков : НТУ "ХПИ". – 2012. – № 10. – С. 139-144.

9 Атаманюк В.М. Кінетика фільтраційного сушіння шлаку теплових електростанцій [Текст] / В.М. Атаманюк, І.Р. Барна // Збірник наукових праць ОНАХТ. – Одеса. – 2012, – Т.2, Вип.41, – С. 89-93.

10 Мосюк М.І. Гідродинаміка і тепломасообмін під час сушіння подрібненої ”енергетичної” верби в стаціонарному шарі [Текст]: Автореф. дис...канд. техн. наук: 05.17.08. / М.І. Мосюк; [НУ Львівська політехніка]. – Львів, 2012. – 22с.

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