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EVALUATION POSSIBILITIES OF CHICKEN MANURE IN TURKEY

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ABSTRACT

Pollution caused by industrial poultry production, which is increasing along with the population growth, is one of the most important environmental problems for developed and developing countries. Particularly in the countries which are leading in the world poultry farming, such as Turkey, share of poultry manure in animal waste is increasing day by day. Due to its amount and characteristics, problems posed by poultry waste are among the priority issues. According to data obtained in 2010, there were 70,933,660 laying hens and 163,984,725 broilers in Turkey and the estimated annual production of fresh manure exceeded 5 million tons. Therefore, development of waste management systems in order to reduce the environmental risks, has become extremely important for poultry industry. Chicken manure causes environmental problems, but also has a significant economic potential. Although there are country-specific methods for the evaluation of chicken manure, evaluation as fertilizer after composting is a common practice across the globe. Also using biogas obtained from waste for the production of energy is one of the common practices. Evaluation of broiler manure as fertilizer in agriculture or burning for heating, are some of the common methods used in Turkey. But in recent years, interest in modern methods such as production of biogas and converting biogas into electrical energy is increasing. In this study, widely used applications for the evaluation of poultry manure in Turkey and development studies of these methods have been examined extensively.

Introduction

Industrial poultry production in Turkey started in the 1980s and developed rapidly with the modern integrated facilities after the 1990s. In the last decades the industry has achieved quality standards at a competitive level with the leading countries (Sarica et al., 2012). Broiler meat production in Turkey showed high growth rates of 14% and 13% in 2010 and 2011 respectively and it was followed by an increase of less than 5% in 2012 but it exceeded 1.8 million tons for 2013. Also in 2012, there were 83,048,395 hens in the total of 3,103 production units at 994 different enterprises. The number of produced eggs in these facilities was 84,677,290 (Yum-Bir, 2013). In total, over 250 million chickens are produced each year. As a result, presently Turkey is a global poultry producer and also one of the most important exporters for the surrounding markets especially in the neighboring countries (USDA, 2013, 2014).

Poultry manure is produced during two main operations of broiler and egg production. Most of the broiler operations result in the production of solid poultry manure, which is referred to as poultry litter or broiler litter. The primary difference between broiler litter and cage layer manure is that the broiler manure is diluted with litter material. Broiler litter is a mixture of manure, bedding material, wasted feed and feathers. Bedding materials are used to absorb liquid fractions of excreta (Edwards and Daniel, 1992). The type of used material depends on locality, but typically includes wood chips, saw-dust, wheat straw, peanut hulls, rice hulls, and recycled paper products. Under most circumstances, this results in a manure containing mixture that is easier to handle because it is usually drier and has fewer problems with odor and insect control than pure manure (Naber and Bermudez, 1990).

Poultry production spent a significant structural evolution with the implementation of a contract manufacturing model and the increase in the number of the integrations, and it has been the biggest part of the Turkish animal production. But, this rapid growth has inevitably resulted in various environmental problems. All poultry wastes have to be well-managed to minimize environmental hazards sourced from the poultry operations. Especially, evaluation of the chicken manure is one of top priority issues for poultry production sector. The waste produced from concentrated poultry operations raises serious concerns for treatment and disposal. A very rough estimate of the amount of poultry manure produced in Turkey is approximately 5.93 million tons (2.99 million tons of this waste from broiler production, 2.94 million from egg production) every year.

During handling and storage of solid poultry manure, a considerable nitrogen (N) loss from ammonia volatilization can occur (Wood, 1992). Because of the phosphorus (P) fraction is readily transported in runoff water during intense rainfall events, dissolved P from fields receiving poultry litter can occur. The chemical composition of poultry manure is important in that it has very direct bearings on the environmental effects of poultry manure as well as the specific applications of poultry manure. Because it is so high in certain macronutrients, excessive land applications can lead to water pollution and soil toxicity. The components of poultry manure cause it to produce various toxic gases as well as noxious odors (Samer, 2013). Also, because of its chemistry, poultry manure is a good fertilizer and can be a very useful, inexpensive feedstuff for animals. Although poultry litter is one of the best organic fertilizer sources available, excessive application of litter can cause environmental problems (Altan et al., 1996).

Poultry manure is usually applied in the immediate vicinity of the production site, where the poultry operations are concentrated. There are several ways in which poultry manure can be collected and processed. Several factors such as the operation size, climate, animal type etc. will determine what type of system is used in what kind of circumstances. It should be noted that in many instances, the strongest influence on the system which is used has the economics of the system. Each system has its own merits and costs, but careful consideration must be used in order to select a system which will make the most efficient use of the factors in which it will be operated. This study provides current information about the usage options of chicken manure in Turkey. These include both recycling and disposal options as well as speeding and incineration. All of these methods of processing poultry manure were viewed under main headings below.

The use of chicken manure as a fertilizer

It has been recognized that poultry manure and litter is a good source of plant nutrient mainly N, P and potassium (K) (Table 1). In addition, poultry waste also contains calcium, magnesium, sulfur and other micronutrients needed for the crops (Oliveira et al., 2012). In a layer system, a typical laying hen will consume feed which contains 1.1 kg N while producing approximately 250 eggs in a year. In a broiler system, a typical broiler year will also consume 1.1 kg N per year of which 0.6 kg N is excreted and 0.5 kg N is assimilated into body tissues. With adequate application rates, animal manure constitutes a valuable resource as a soil fertilizer, as it provides a high content of macro and micronutrients for crop growth and represents a low-cost, environmentally friendly alternative to mineral fertilizers.

Table 1
Chemical composition of poultry litter

Macronutrients	($g \cdot 100\ g^{-1}$)	Micronutrients	($\mu g \cdot g^{-1}$)
Nitrogen (N)	2.08	Copper (Cu)	303
Phosphorus (P)	1.01	Iron (Fe)	1,786
Potassium (K)	2.61	Manganese (Mn)	294
Calcium (Ca)	2.08	Zinc (Zn)	217
Magnesium (Mg)	0.53	Sodium (Na)	2,629
Sulfur (S)	0.028	Lead (Pb)	22

Oliveira et al., 2012

Even with its beneficial effects on plant growth, however, manure constitutes only a small percentage of the nutrients applied to cropland when compared to commercial fertilizer. On the other hand, many environmental problems of current concern are due to the high production and local accumulations of organic wastes that are too great for the basic degradation processes inherent in nature. The primary reason behind this is that there are dangers to over application of poultry manure to fields. The EU Nitrates Directive caps organic manure applications to land at 170 kg organic N/ha. Most poultry farms operate far above this limit and it is estimated that more than 90% of poultry litter has to be exported off the home farm. The potentially adverse effects of such indiscriminate applications include an excessive input of harmful trace metals, inorganic salts and pathogens;an increased nutrient loss, mainly nitrogen and phosphorus, from soils through leaching, erosion and runoff-caused by a lack of consideration of the nutrient requirements of crops; and the gaseous emissions of odors, hydrogen sulphide (H_2S), ammonia (NH_3) and other toxic gases. In fact, the agricultural contribution to total greenhouse gas emissions is around 10%, with livestock playing a key role through methane emission from enteric fermentation and through manure production. More specifically, around 65% of anthropogenic nitrous oxide

(N_2O) and 64% of anthropogenic NH_3 emissions come from the worldwide animal production sector.

Many poultry breeders have managed this manure by spreading it on fields without any treatment traditionally. Undoubtedly, spreading waste in the fields is the easiest and cheapest option for disposal of chicken manure, and this method has been widely practiced for a long time in Turkey as well. Combination of industrial production and the diminishing amount of manure spread fields resulted in more manure than crops can use, the excess minerals flowed into the streams or ground waters. Surface and ground water pollution, accumulation of the trace elements, problems with odors and flies are common problems associated with over-application (Altan and Bayraktar, 1998).

Poultry litter has a relatively high dry matter (DM) content, but is P rich. As this P originates from imported cereals it contributes to the P surplus of local agriculture. Nitrate leaching into the groundwater, nonpoint source P runoff into surface water bodies, and release of pathogenic microorganisms are three of the main problems encountered with improper management of this resource. An analysis of the used litter for nitrogen, phosphorus and potassium should be used as the basis for the application rate to soils. In most cases, the dilution of the manure with litter means that substantially higher rates of application of the applied litter can be used than those previously suggested for cage layer manure.

Composted chicken manure can be used as a fertilizer with or without balancing as well, and it provides good results in soils suffering from depletion of organic contents for amendments (Bayraktar and Altan, 1998). Even though composting has not been widely recognized as an alternative method to evaluate chicken manures yet, some of the poultry integrations has produced more manure in last years. An increase could be expected in the number of composted chicken manure producers in the near future.

The use of chicken manure as a feed for ruminants

Ruminants have a unique digestive system that allows them to use waste and other types of by-products as sources of dietary nutrients. The cattle-feeding industry has been built largely on the use of by-products and other materials that can be digested only by ruminants. Micro-organisms in the rumen have the unique ability to utilize uric acid and other forms of non-protein nitrogen (NPN) contained in the waste to make their own body protein which is subsequently digested in the lower gut for use by the host animal. The rumen microbes also degrade cellulosic materials used as a bedding contained in the waste. One of the by-products that can be used as a cattle feed was chicken manure. Even though literature on this issue is vast, there is no report on using chicken manure as a feed for ruminants in Turkey. At the same time using poultry waste in feed is not a legal practice according to the regulations of the Ministry of Food, Agriculture and Livestock.

The use of poultry waste as a feed additive for ruminants is an old practice. U.S. Food and Drug Administration (FDA) estimates that farmers feed 1 million to 2 million tons of poultry litter to their cattle annually in the USA. However, in recent times, the dangers of such practice have become more apparent and these practices become to be prohibited in some countries. Also, using the chicken manure as a feed for ruminants increases the risk of cows becoming infected with bovine spongiform encephalopathy (BSE), or mad cow disease. Although it is rare, people can contract a fatal form of the disease by eating meat from cows with BSE. Animal Welfare Approved (AWA) standards prohibit the feeding of animals with processed industrial chicken waste or any other unnatural feed (Animal By-Products Statement, 2012). Also poultry litter can contain a range of disease-causing bacteria which cattle can transmit to humans, such as campylobacteria, salmonella and E. coli, as well as veterinary drug residues or moulds and yeasts.

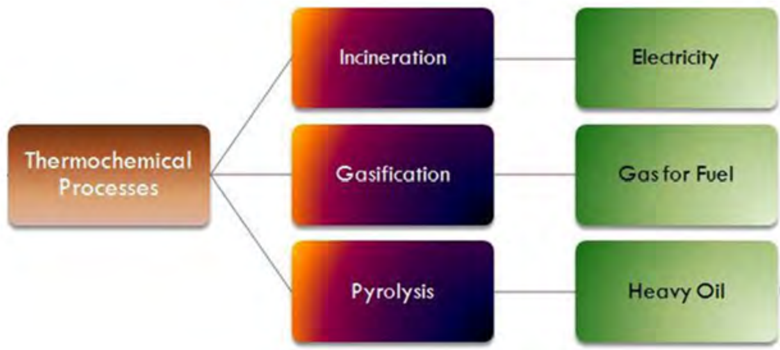
The use of chicken manure as a fuel

Although some of power plants operate using poultry litter in the UK, large scale incineration of poultry waste is not common practice in Turkey. Only some local broiler breeders at Ege and Marmara region of Turkey has used broiler litter with little rates in solid fuel stoves for heating. Because of the tiny parts of total manure it can be used as a fuel, manure burning is not mentioned as an alternative method for Turkey. On the other hand nearly 20% of the electric energy comes from thermal reactors. If some of chicken manure might be used as an alternative fuel source for these reactors, significant amounts of broiler litter can be burned.

Broiler production requires energy for heating houses nearly through the whole year. Heat energy obtained in the burning process of fossil fuels and biomass cause the greenhouse gas (GHG) emissions. Incineration of poultry litter has been receiving a lot of attention in the recent times. Litter (unlike manure) is an excellent fuel because of the presence of bedding material. Its heat content is higher than firewood and therefore lends itself to good combustion. Poultry litter has an approximate BTU value ranging from 7,900 to 17,300 per kg depending on the moisture content, while coal has an average BTU value of 22,000 – 34,200 per kg. Typical poultry litter has a moisture content of around 30%. For this reason, adding more wood chips into the poultry litter to ensure more consistent heat energy is suggested. A combination of 30% wood chips and 70% chicken litter was recommended. From July 15, 2014 all poultry farmers across the EU will be allowed to combust poultry litter on-farm to create energy. Thus, biomass is no "green energy", poultry waste is not a clean fuel.

Combustion technology is the controlled combustion of waste with the recovery of heat to produce steam which in turn produces power through steam turbines. Pyrolysis and gasification represent refined thermal treatment methods as alternatives to incineration and are characterized by the transformation of the waste into product gas as energy carrier for later combustion in, for example, a boiler or a gas engine (Figure 1).

Biomass pyrolysis has been garnering much attention due to its high efficiency and good environmental performance characteristics. It also provides an opportunity for the processing of agricultural residues, litter or chicken manure into clean energy (Oliveira et al., 2012). In addition, biochar sequestration could make a big difference in the fossil fuel emissions worldwide and act as a major player in the global carbon market with its robust, clean and simple production technology.



Zafar, 2014

Figure 1. The principal methods of thermochemical conversion

The use of chicken manure in biogas production

Manure is the largest and cheapest resource for biogas production. The anaerobic digestion process has an environmental advantage compared to burning of organic wastes. Biogas technology is one of the most environmentally friendly production methods from biomass by the anaerobic fermentation process, as it is usable for a relatively "clean" heat and power energy production, as the biogas contains no ashes.

Biogas is a potentially important energy source that can be used for the production of heat, electricity and fuel. It can be produced at wastewater treatment plants, landfills, food and other industrial operations throughout the world. There is a largely untapped potential in agricultural operations where animal waste is often land applied or otherwise disposed of without conversion to energy.

Controlled combustion in a power plant converts virtually all of the carbon in the biomass to carbon dioxide (CO_2). As methane (CH_4) is a stronger greenhouse gas than CO_2, shifting CH_4 emissions to CO_2 by converting biomass residues to energy significantly reduces the greenhouse warming potential of the recycled carbon. Anaerobic treatment of manure reduces emissions of methane and other harmful substances into environment to great extent. Also it appears to offer solution to the environmental problems and the energy shortage. But, higher financial investments and considerably management knowledge requirements reduce the practicality of this method. Other disadvantages are the amount of management required due to the sensitivity of the digesters, the high initial investment required for equipment, and the fact that the wastes still must be disposed of after digestion.

According to the last agricultural census in Turkey, there are a total of 3,076,650 agricultural enterprises and approximately 70% of these enterprises are running livestock farming. 10,811,165 of total animal is cattle, 26,877,793 of total animal is small ruminant and 234,082,206 is poultry. The amount of wet waste of these animals is about 120,887,280 t. These wastes could be a major problem for enterprises and cannot be utilized properly. The best way to utilize waste is to produce biogas. In this study, biogas amount which will be obtained from animal waste was calculated for all provinces by using the number of livestock animals and also considering various criteria such as the rate of dry matter and availability. Animal origin waste map of Turkey was also produced with these calculated values (Figure 2). The biogas energy potential of Turkey was found to be 2.18 Gm^3 by using the animal number in the last agricultural census. The total biogas potential is originated from 68% cattle, 5% small ruminant and 27% poultry. The biogas potential of Turkey calculated from the number of chicken is 390 million m^3. The biogas energy from poultry waste equivalence of Turkey is approximately 8.853 million GJ. When the chicken waste map of Turkey is examined, provinces that have more than 10 million m^3 biogas potential are found to be Bolu, Balikesir, Sakarya, Manisa, Afyon, Konya, Izmir, Ankara, Corum and Bursa (Avcioglu et al., 2013).

The calculated regional biogas potential from animal manures is about 3,275 million m^3, including 40.01% from large animals 47.14% small animals, 12.85% from poultry (Table 2).

Avcioglu et al., 2013

Figure 2. Amount of chicken manure according to the provinces in Turkey

Table 2
Biogas Energy Potential of Turkey

Animal kind	Number of animals	Total amount of manure (1000 t·$year^{-1}$)	Amount of available biogas (1000 m^3·$year^{-1}$)	Available biogas (%)
Large animals	11,054,000	39,794.4	1,313,215.2	40.01
Small animals	38,030,000	26,621.0	1,544,018.0	47.14
Poultry	243,510,453	5,357.2	417,863.9	12.85
Total	292,594,453	71,772.6	3,275,097.1	100

Demirel et al., 2010

At the beginning of the 2010s, there are many biogas plants constructed but some of them were successfully in Turkey (Table 3). At the moment, 5 power plants producing energy from landfill gas with license exist. In addition, 9 biogas plants have obtained license for electricity production with a total production capacity of 17.59 MW. Four of these plants are operating now, with a total production capacity of 6.12 MW (Demirel et al., 2010).

Table 3.
Companies which obtained a biomass based on biogas

Company Name	License Type	Location	Installed Capacity (MW)
Cargill Tarim	Auto Producer	Bursa	0.12
Yeni Adana	Auto Producer	Adana	0.8
GASKI Enerji	Auto Producer	Gaziantep	1.66
ESES Eskisehir	Auto Producer	Eskisehir	2.042
Konbeltas Konya	Generation	Konya	2.434
Mersin Metropolitan	Generation	Mersin	1.9
Samsun Avdan	Generation	Samsun	2.472
Pamukova Renewable Energy	Generation	Sakarya	1.4
IZAYDAS	Generation	Kocaeli	0.7
Sigma Elektrik	Generation	Amasya	2
Derin Enerji	Generation	Ankara	0.576
Her Enerji	Generation	Kayseri	1.56

Yazgan, 2013

Conclusions

When properly managed, poultry litter provides an excellent source of plant nutrients and organic matter for application to field and cropland. Poultry manure fertilizer contains all the essential nutrients required for crop production, and its value as an organic fertilizer and a source of plant nutrients has been recognized for centuries. It will also look into the environmental impact of poultry manure production as well as some management aspects. Each system of collection, handling and processing has its own merits and uses. The relationship between good waste management and sustainable production management must be well analyzed. Properly managed manure applications improve soil quality, recycle nutrients to crops, and minimize the water pollution. One of the most promising ways for aerobic processing of poultry manure is by composting it. Composting is a relatively fast aerobic process in which organic matter is degraded by bacteria and fungi to produce a relatively stable humus-like material.

Turkey is theoretically capable to produce biogas from poultry waste. In this context, the new objective for the near future can be increasing the share of the renewable energy sources from biomass to minimize detrimental effects of animal waste. Production of biogas from different types of biomass offers great opportunities to reduce emissions from poultry waste and therefore to protect the environment.

Slurry on the base of poultry manure management can be a new alternative for Turkey. Anaerobic lagoons are created from manure slurry, which is washed out from underneath the animal houses and then piped into the lagoon. Vermicompost production is another alternative method, and has been already experimentally used for animal manures (Lazcano et al., 2008).

Ultimately, alternative methods and technologies will help us to understand the importance of stabilization of organic matter and minimize the potential risks related to the use of animal manure as an organic amendment.

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MOŻLIWOŚCI OCENY ODCHODÓW KURZYCH W TURCJI

Streszczenie. Zanieczyszczenia pochodzące z przemysłowej produkcji drobiu, których ilość wzrasta wraz ze wzrostem populacji, jest jednym z najważniejszych problemów środowiskowych w krajach rozwiniętych i rozwijających się. Szczególnie w krajach, które przodują w hodowli drobiu, takich jak Turcja, udział odchodów kurzych w odpadach zwierzęcych rośnie z dnia na dzień. Ze względu na ilość i charakterystykę, problemy stwarzane przez odpady pochodzenia kurzego znajdują się wśród najważniejszych. Według danych z 2010, Turcja posiadała 70 933 660 kur niosek oraz 163 984 725 brojlerów a szacowana roczna produkcja świeżego nawozu przekraczała 5 milionów ton. Zatem, rozwój systemów gospodarki odpadami w celu zmniejszenia ryzyka środowiskowego stał się bardzo ważny dla przemysłu drobiowego. Odchody kurze są źródłem problemów środowiskowych, ale także posiadają istotny potencjał ekonomiczny. Mimo, że istnieją krajowe metody oceny odchodów kurzych, ich ocena jako nawozu po kompostowaniu jest popularną praktyką na całym świecie. Ponadto, popularną praktyką jest także zastosowanie biogazu otrzymanego z odpadów na cele energetyczne. Ocena odchodów brojlerów jako nawozu w rolnictwie lub źródła ciepła jest często stosowaną metodą w Turcji. Jednakże, w ostatnich latach, zainteresowanie nowoczesnymi metodami takimi jak produkcja biogazu i przekształcanie biogazu w energię elektryczną stale wzrasta. Niniejsza praca skupia się na gruntownej analizie oceny odchodów kurzych w Turcji i badań rozwojowych nad metodami oceny.

Słowa kluczowe: odchody kurze, gospodarka odpadami, biogaz, energia

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EVALUATION OF THE IMPACT OF DIGESTATE FORMED DURING BIOGAS PRODUCTION ON THE CONTENT OF HEAVY METALS IN SOIL

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ABSTRACT

The aim of the study was to identify and assess the impact of four digestive masses obtained from different organic substrates on the content of heavy metals in soil. The study utilized soil derived from fertilizer and equipment. Timothy grass was used as a test plant. The effect of a fertilizer on the analyzed mass was compared with the objects of reference, which were: a control object (without fertilization), fertilized objects with the use of ammonium nitrate, fresh pig slurry and mineral fertilizer YaraMila. Experiment was conducted in quadruplicate, consisting of the total of 76 objects. Based on the survey, it was found that the use of digestive for fertilizing purposes is justified because of its impact on various soil parameters and is comparable to the impact of traditional fertilizers such as manure, ammonium nitrate and mineral compound fertilizers. The use of the digestive did not cause greater accumulation of heavy metals in the soil, than it is in case of the use of ammonium nitrate fertilizer or fresh manure, which further confirms that these products are safe and can be applied alternatively with traditional fertilizers.

Introduction

In Poland and other countries a growing interest in the construction of agricultural biogas plants has been reported recently. The energy produced from renewable sources becomes more and more popular because of environment protection proposals. However, along with this interest, a problem occurs. It is related to management of digestive, which is a by-product of the biogas production. The best and the cheapest way, is to use it for farming as a fertilizer. Unfortunately, it is difficult to convince farmers to use products from the biogas plant.

Waste from an agricultural biogas plant can be a good fertilizer, taking into account that they are properly managed. Research carried out on the digestive shows that its use for the purpose of fertilization is justified because of its proper effect on various parameters of the soil and is comparable to the effect of conventional fertilizers, such as liquid manure, ammonium nitrate and mineral fertilizers.

In the absence of data in literature concerning properties of the digestive fertilizer the aim of this study was to assess the impact of the use of different types of post fermented material on heavy metals content in soil. The study presents an analysis of their impact on the yield and general crop characteristic.

Properties of the digestive material

The unfermented organic compounds are mainly minerals and methane bacteria that remained after the process of anaerobic digestion. It is also known as residues of fermentation, digestive pulp, effluent or sewage digestive. Composition of the digestive material depends primarily on substrates involved in the process of anaerobic digestion.

After the anaerobic fermentation, a digestive mass is directed to the digester's storage tanks (liquid manure lagoons)._There, digestive material is stored and cooled. The fermentation process also takes place next to digestive storage tanks._This makes it possible additionally to obtain up to 20% of extra biogas. Moreover, covered tanks limit emission of odors to the environment.

Due to low total solids content in digestive material (within the range of 3 to 10%), currently it often happens that the digestive solid fraction is separated from the liquid fraction, which reduces the total volume of the fermented material. The solid fraction, prior to further use, can be stored and composted, while the liquid one may be used as a fertilizer or returned to a digester as a treatment dilute reactant. For separation of the two fractions, a belt filter press or a centrifuge is applied. The solid fraction after passage through a filter press may contain approximately up to approx.. 30% of dry matter content. In this form it can be applied for crop fields or grassland.

Table 1 shows the content of heavy metals in the digestive material obtained by anaerobic digestion from liquid manure divided into fractions. The results of laboratory experiments indicate that mass of the digestive compound compared to liquid manure used as starting material has practically the same quantities of Mn, Fe, Cu and Zn.

Table 1

Chemical properties of digestive material obtained from fermentation liquid manure, taking into account heavy metals content

Specification	Mass of the digestive material		
	The digestive liquid manure before separation into fractions	Liquid fraction	Solid fraction
Total solids (%)	1.6	1.5	32.6
Fe ($g \cdot kg^{-1}$ d.m.)	4.0	4.3	4.1
Cu ($mg \cdot kg^{-1}$ d.m.)	1016	1001	170
Mn ($mg \cdot kg^{-1}$ d.m.)	708	610	1042
Zn ($mg \cdot kg^{-1}$ d.m.)	2628	2563	519

Source: Szymańska, 2011; Marcato et al., 2008

Depending on the type of reactants involved in the process of anaerobic digestion, a chemical composition of digestive material was varied. Most of the agricultural biogas plants as the primary substrate for the production of biogas utilize liquid manure or corn silage. On the basis of analysis of reactions that occur during the anaerobic digestion, physical and chemical properties of the digestive material can be generally defined. It is important to evaluate the value of trace microelements content, including heavy metals. Table 2 presents the results of the zinc and copper content in different masses of the digestive material. The results indicate that the highest content of zinc and copper occurred in the mass of the digestive material marked with PS-AB2 (pig liquid manure and pasteurized slaughterhouse waste – 3.8%), and the lowest in CS-AW1 (cattle liquid manure and orange peel residues – 5%).

Table 2
Heavy metal content in the mass of digestive material

Symbol of the digestive material	Zn ($mg \cdot l^{-1}$)	Cu ($mg \cdot l^{-1}$)
PS-EC1	49.2	8.4
PS-EC2	45.9	7
PS-EC3	62.5	7.8
PS-AB1	84.4	14.3
PS-AB2	140.2	15.1
PS-AB3	34.7	4
Average	55.8	8.1
CS-G1	18.1	10.8
CS-G2	28.3	13
CS-G3	10.6	1.4
CS-AW1	7.7	2.8
CS-AW2	8	3,1
CSAW3	27.7	10.8
Average	14.4	6.9

Source: Szymańska, 2013; Alborquerque et al., 2012

where:
1) Group 1: pig liquid manure + add-energy plants
• PS-EC1 – pig liquid manure + rapeseed residue (9.6%),
• PS-EC2 – pig liquid manure + sunflower residue (4.5%),
• PS-EC3 – pig liquid manure + maize residues (5.4%).
2) Group 2: pig liquid manure + animal waste
• PS-AB1 – pig liquid manure + pasteurized slaughterhouse waste (0.6%),
• PS-AB2 – pig liquid manure + pasteurized slaughterhouse waste (3.8%),
• PS-AB3 – pig liquid manure + sludge from the wastewater treatment plant from slaughterhouses (1%) + the biodiesel wastewater (6.5%).
3) Group 3: cow liquid manure + addition of glycerol
• CS-G1 – cow liquid manure and glycerin (4%),
• CS-G2 and CS-G3 – cow liquid muck + glycerol (6%).
4) Group 4: cow liquid manure + additive residues from the agro-industrial
• CS-AW1 – cow liquid manure + orange peel residue (5%),
• CS-AW2 – cow liquid manure + orange peel residues (10%),
• CS-AW3 – cow liquid manure + cow slurry (4.3%) + oats and corn silage (11.6%).

Some of the substances included in biomass, even in small amounts can contain very harmful bacteria which may stop the process of anaerobic digestion. They are divided into toxic substances, which can get into the fermentation chamber together with a substrate as well as into those which go as intermediates in various stages of anaerobic decomposition. Excessive amount of a substrate can lead to distortion or inhibit the fermentation process through adverse effects on bacteria. Trace elements may also affect bacteria in a toxic way, if they occur in high concentrations. Extremely harmful substances are heavy metals, disinfectants, solvents, herbicides, salts and antibiotics. Heavy metals in a free form are harmful to the process of methane fermentation and later they can stay in the digestive material. Hydrogen sulfide can neutralize heavy metals during the fermentation process; therefore, the amount of harmful elements in a fermentation chamber can be reduced. If the concentration of hydrogen sulfide exceeds 50 $mg \cdot l^{-1}$ it can cause inhibition of the fermentation process. Increased concentration of hydrogen sulfide in biogas also contributes to corrosion of thermal energy systems.

The use of fertilizer from digestive material derived from the fermentation liquid manure, solid manure, biomass and other organic matter of the agricultural industry has a very good effect on physical and chemical properties of the soil, the environment and profitability. The mass of the digestive material can also be enriched by addition of macro- or micronutrients, creating organic and mineral fertilizers, which can be adapted to the requirements of various plants (Szymańska, 2013; Podkówka, 2012; Szymańska, 2011; Baadstrop, 2011; Kowalczyk-Juśko, 2010; Borowski and Domański 2009; Palm, 2008; Montusiewicz, 2008; Głodek et al., 2007; Ledakowicz and Krzystek 2005; Romaniuk, 1999).

Research material

The study was based on the experiment using set of pots, and was conducted in the greenhouse Experimental Station of the Faculty of Agriculture and Biology at the University of Life Sciences in Skierniewice. The study utilized sustainable soil fertilizer experiments and timothy grass was used as test plant. Digestive materials of symbols MP1, MP2, MP3, MP4 were mixed with 7.0 kg of soil before sowing timothy grass in doses consistent with the scheme of experiments (tab. 3). Some vases were sown with timothy (without presowing fertilization) and during the growth 50 ml to each of the tested masses were added to each vase (tab. 3).

Digestive material samples were taken from the laboratory fermentation chambers. Four digestive materials, differing with substrates used for fermentation, were selected for the tests (tab. 4). The fertilizer effect of the analyzed digestive material was compared with the reference objects, which were:

- Controls object without fertilization,
- SA1, SA2 – objects fertilized with ammonium nitrate,
- G1, G2 – objects fertilized with fresh pig liquid manure,
- YM1, YM2 – objects fertilized with mineral YaraMila.

Experiment was conducted in quadruplicate with 76 vases.

Table 3
Experiment data

Objects	Symbol of the digestive material	Dose	Unit
1	Control	0	-
	Pre-sowing fertilization		
2	$MP1_1$	100	$ml\cdot vase^{-1}$
3	$MP1_2$	150	$ml\cdot vase^{-1}$
4	$MP2_1$	100	$ml\cdot vase^{-1}$
5	$MP2_2$	150	$ml\cdot vase^{-1}$
6	$MP3_1$	100	$ml\cdot vase^{-1}$
7	$MP3_2$	150	$ml\cdot vase^{-1}$
8	$MP4_1$	100	$ml\cdot vase^{-1}$
9	$MP4_2$	150	$ml\cdot vase^{-1}$
10	G1	100	$ml\cdot vase^{-1}$
11	G2	150	$ml\cdot vase^{-1}$
12	SA1	0.75	$g\cdot vase^{-1}$
13	SA2	1.5	$g\cdot vase^{-1}$
14	YM1	2.1	$g\cdot vase^{-1}$
15	YM2	4.2	$g\cdot vase^{-1}$
	Extra fertilization		
16	MP1	50	$ml\cdot vase^{-1}$
17	MP2	50	$ml\cdot vase^{-1}$
18	MP3	50	$ml\cdot vase^{-1}$
19	MP4	50	$ml\cdot vase^{-1}$

where:
Controls – object without fertilization
- MP1 – liquid manure (67%) + leaves the head (22%)
- MP2 – liquid manure (87%) + glycerol (13%)
- MP3 – liquid manure (67%) + mushroom substrate (22%)
- MP4 – 100% liquid manure,
- G1 and G2 – fresh manure,
- SA1 and SA2 – ammonium nitrate,
- YM1 and YM2 – YaraMila fertilizer.

Table 4
Fermentation material used in the pot experiment (material was obtained from the Poznan University of Life Sciences in a joint research project)

Symbol of the digestive material	Utilized material for fermentation of substrates	% participation in the batch
MP1	liquid manure	67
	leaves	22
MP2	liquid manure	87
	glycerol	13
MP3	liquid manure	67
	mushroom substrate	22
MP4	liquid manure	100

Research methodology

After the end of the vegetation period, soil samples were taken from each vase. The soil was sieved through a 2 mm sieve. Then air-dried soil samples heavy metals were determined (Zn, Cu, Fe, Mn) in 1 mol·dm^{-3} HCl by AAS.

The results were statistically analyzed using Statistica 10.0 software. A multi-variant analysis was performed and homogeneous Tukey HSD test groups were separated at the significance level of $\alpha = 0.05$.

Research results

When assessing the suitability of various types of waste and industrial by-products, including digestive material for use as a fertilizer, an important aspect is to check the impact of the use of this "product" on the accumulation of heavy metals in soil. For this reason, the present study was carried out by soil analysis concerning copper, zinc, iron and manganese content. The choice of heavy metals was justified by the fact that digestive material typically contains substantial quantities of those metals. Thus, the soil application may lead to the accumulation of the mentioned heavy metals. The presence of heavy metals in post fermentation residues is mainly due to the addition of the pig liquid manure fermentation process, and therefore the use of digestive material should not increase the content of heavy metals in the soil more than the use of traditional liquid manure. The results confirm this hypothesis. Indeed, there was no statistically significant difference between the content of Cu, Zn, Fe and Mn in soil where the tested digestive materials were applied and soil where typical liquid manure was used. In addition, these results indicate that the content of the mentioned heavy metals on objects fertilized with digestive material does not differ from the content in the soil in the control object (Table 5). It can therefore be concluded that the fertilization digestive material is safe and does not cause the accumulation of heavy metals in soil.

Based on the results shown in table 5 it can be concluded, that in comparison to the control, the highest content of zinc was in soil fertilized with digestive material MP 3 with (liquid manure – 67% and mushroom substrate – 22% in the dose of 150 ml) and soil fertilized with ammonium nitrate in 1.5 g dose.

The lowest copper content was in case of the sample fertilized with post-fermented material MP2, which contained in its composition liquid manure – 87%, glycerol 13% and the fertilizer applied in 150 ml dose. The highest copper content in a digestive material was in case of 100% liquid manure, which was used in the extra fertilization in 50 ml dose.

The lowest content of iron in the soil in comparison to the control sample was in case of those containing ammonium nitrate in 1.5 g dose and samples digestive MP2, which contained liquid manure – 87% and glycerol – 13%, in 50 ml dose of extra fertilization. The highest content of this element was in MP1 sample, which contained liquid manure – 67% and leaves – 22%, in 100 ml dose, and a fresh liquid manure in 150 ml dose.

The smallest manganese content was determined in MP3 samples, which contained liquid manure – 67% and mushroom substrate – 22%, with the dose of 150 ml and SA1 (ammonium nitrate in 0.75 g dose). The highest manganese content was detected in MP1 samples, which contained liquid manure – 67% and leaves – 22% in 50 ml dose and SA2 ammonium nitrate in 1.5 g dose.

Table 5
Content of heavy metals in soils (mg·kg^{-1})

Test objects	mg Zn·kg^{-1}			mg Cu·kg^{-1}			mg Fe·kg^{-1}			mg Mn·kg^{-1}		
Soil output	4.52			1.66			2146.89			36.93		
Controls	4.95			1.73			2293.35			32.66		
Objects fertilized with traditional fertilizers												
The term fertiliza-tion	Pre-sowing fertilization			Pre-sowing fertilization			Pre-sowing fertilization			Pre-sowing fertilization		
Dose	1 dose		2 doses	1 dose		2 doses	1 dose		2 doses	1 dose		2 doses
Liquid manure	5.07		5.73	1.73		2.01	2468.34		2707.77	38.65		35.38
Ammo-nium nitrate	5.21		5.88	1.79		1.66	2299.74		2244.49	32.32		43.97
YaraMila	5.05		5.03	1.90		1.84	2351.60		2462.40	35.16		33.35
Objects fertilized of the digestive material												
Term fertiliza-tion	Pre-sowing fertiliza-tion		Extra fertiliza-tion	Pre-sowing fertiliza-tion		Extra fertiliza-tion	Pre-sowing fertilization		Extra fertiliza-tion	Pre-sowing fertilization		Extra fertili-zation
Dose	100 ml	150 ml	50 ml	100 ml	150 ml	50 ml	100 ml	150 ml	50 ml	100 ml	150 ml	50 ml
MP1	5.76	5.22	5.24	1.94	1.74	1.95	2581.38	2438.75	2292.54	39.34	37.24	34.07
MP2	5.60	5.35	5.53	1.60	1.58	1.77	2432.37	2361.32	2247.24	34.64	37.89	34.17
MP3	5.44	5.80	5.25	1.69	1.92	1.97	2381.22	2460.64	2558.01	35.77	32.25	38.00
MP4	5.56	5.59	5.12	1.77	1.76	2.02	2318.53	2272.22	2342.36	34.27	36.34	34.63

Discussion and conclusions

On the basis of experiments it was concluded that the use of the digestive material as a fertilizer does not cause an increased accumulation of heavy metals in soil than it is in case of ammonium nitrate or fresh liquid manure.

In addition, the results of the study showed that the contents of heavy metals (Cu, Zn, and Mn Fn) in soil fertilized with the post fermented material used in the site experience did not differ from the contents of the control objects.

It can be concluded that fertilization using digestive material is safe and does not cause the accumulation of heavy metals in a soil.

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OCENA WPŁYWU MASY POFERMENTACYJNEJ POWSTAJĄCEJ PODCZAS PRODUKCJI BIOGAZU NA ZAWARTOŚĆ METALI CIĘŻKICH W GLEBIE

Streszczenie. Celem pracy było określenie i ocena wpływu stosowania czterech materiałów pofermentacyjnych uzyskanych z różnych substratów organicznych na zawartość metali ciężkich w glebie. Do badań wykorzystano glebę pochodzącą z trwałych doświadczeń nawozowych. Rośliną testową była trawa tymotka. Efekt nawozowy analizowanych mas porównywany był z obiektami odniesienia, do których należały: kontrola (obiekt bez nawożenia), obiekty nawożone saletrą amonową, świeżą gnojowicą świńską oraz nawozem mineralnym YaraMila. Doświadczenie prowadzone było w czterech powtórzeniach, łącznie obejmowało 76 obiektów. Stosowane masy pofermentacyjne nie spowodowały większego gromadzenia metali ciężkich w glebie, niż ma to miejsce w przypadku stosowania saletry amonowej czy świeżej gnojowicy, co dodatkowo potwierdza, że są to produkty bezpieczne i mogą być alternatywą dla tradycyjnych nawozów.

Słowa kluczowe: biogaz, fermentacja metanowa, nawozowe wykorzystanie masy pofermentacyjnej, doświadczenie wazonowe

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THE REQUIREMENT FOR NEW BIOMASS PELLETIZING TEST DEVICE

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ABSTRACT

As the bulk density of biomass material is low, some problems are encountered during storage, transport and usage of biomass. In order to overcome these problems, densification process is necessary to increase the bulk density of the biomass. Biomass characteristics are improved, the volumetric heating value of biomass is increased, transportation and storage costs of biomass are reduced and the combustion characteristics of biomass are improved by a biomass densification process. Nowadays, pelletizing machines are widely used in the course of biomass densification. During the pelletizing machine's operation, obtaining the high quality compressed biomass with high capacity and less energy consumption is closely related to the pelletizing machine's design criteria. Therefore, it is necessary to investigate all parameters that affect the pelletizing machine performance. In a laboratory scale, biomass pelletizing and densification tests are carried out by means of simplified pelletizing apparatus. Unfortunately, the tests that are executed by means of these apparatus, because of their operation principle, can not completely illustrate the pelletizing process and the forces which occur during this process. As the current systems which are used to simulate the pelletizing process are not sufficient, in order to clarify, model and optimize the pelletizing process much more effectively and to obtain necessary reliable data for pelletizing machine design, development of a new apparatus is necessary. The requirement of developing a new biomass pelletizing test device and its design principles are explained in this study.

Introduction and objective of the paper

Biomass is the third-largest energy resource in the world, after coal and oil (Bapat et al.,1997). Biomass was the main energy resource of the world until the mid-19th century. Accordingly, within the past 50 years, the consumption of biomass for energy purposes has decreased sharply, because of the increase in fossil fuel usage and technologies. Despite these, biomass still provides about 1,250 million tons of oil equivalents and supplies about 14% of the world's annual energy consumption (Purohit et al., 2006; Werther et al., 2000; Zeng et al., 2007). If the biomass consumption is managed properly, it offers many advantages. The most important advantages of biomass consumption are its renewability and sustainability, and can significantly reduce net carbon emissions when compared with fossil fuels. Many of the developed and industrialized nations carry out research and development activities in order to use biomass energy resource more efficiently.

Because of these research and development activities, in the USA and most of Europe, biomass is already a competitive resource for energy production. The USA and Sweden obtain about 4% and 13% of their energy, respectively, from biomass (Hall et al. 1992).

Biomass and agricultural residues are one of the important resources for supplying energy needs, especially for developing countries. Agricultural residues are low-density materials with high moisture contents. So, their direct use at homes and in industrial areas will not be efficient. Moreover, because of their physical properties, some problems occur during biomass transport, storage and usage. One of the major limitations of biomass as energy source is its low density, typically ranging from 60-80 $kg \cdot m^{-3}$ for agricultural straws and grasses and 200–400 kg/m^3 for woody biomass like wood chips (Sokhansanj et al., 2006; Mitchell et al., 2007).

These low densities often make biomass material difficult to store, transport, and utilize. For example, when this type of low density biomass is co-fired with coal, the difference in density between biomass and coal causes problems in feeding the fuel into the boiler and reduces burning efficiencies.

In order to use biomass energy source effectively, the density of biomass must be increased. Commercially, the biomass densification process is done by using pellet mills to increase the density of biomass by about tenfold and help overcome feeding, storing, handling, and transporting problems. Pelletizing of biomass is a mass and energy densification for materials that possess low bulk densities such as sawdust, straw and other herbaceous energy crops.

Pelletizing is a method of increasing the bulk density of biomass by mechanical pressure. The process reduces transportation costs, provides better handling and feeding of the biomass and efficient storage with less dust formation. There are two main types of pellet presses: a ring die and a flat die. Various commercial pellet mills are shown in Figure 1.

In commercially manufactured pelletizing machine, the incoming feed from the feeder is delivered uniformly to the conditioner to control addition of steam or binders to improve the pelletizing process. The feed from the conditioner is discharged into the pelletizing die. Biomass pellets are formed in a pelletizing chamber by compacting and forcing through die openings by rollers in a mechanical process. Small rotating rolls push the feed material into die holes from inside of the ring towards the outside of the ring. The skin friction between the feed particles and the wall of the die resists the free flow of feed and thus the particles are compressed against each other inside the die to form pellets. One or two adjustable knives placed outside the ring cut the pellets into desired lengths (Tumuluru et al., 2010).

As it is known, the key to obtain densified biomass with a desired quality is controlling the densification system variables. Specifically, the quality of the densified product can be managed by controlling conditions such as the manufacturing process, changes in formulation, and the use of additives (MacMahon, 1984). In addition, process variables such as die thickness, retention time, rolls die ring gap (Wetzel, 1985), steam conditioning, and feed rate (MacMahon, 1984) affect the qualities of densified biomass such as density and durability. The densified biomass quality directly depended on the process variables of pelletizing such as: die diameter, die temperature, pressure, binder usage, and biomass pre-heating.

Shaw (2008) identified that the process variables (die temperature, pressure, and geometry) feedstock variables (moisture content and particle size and shape) and feedstock composition (protein, fat, cellulose, hemicelluloses and lignin) all impact the quality of the densified biomass.

Figure 1. Typical Pelletizing Machines

Mani et al. (2002) postulated that there are three stages of biomass densification. In the first stage, particles rearrange themselves to form a closely packed mass where most of the particles retain their properties and the energy is dissipated due to inter-particle and particle-to-wall friction. In the second stage, the particles are forced against each other and undergo plastic and elastic deformation that significantly increase the inter-particle contact promoting bonding through vanderwaal's and electrostatic forces. In the third phase, higher pressures significantly reduce the volume until the density of the pellet approaches the true density of the component ingredients. By the end of the third stage, the deformed and broken particles can no longer change their position due to a decreased number of cavities and achieve 70% inter-particle conformity (Fig. 2).

As it is known, it is necessary to evaluate all effective parameters on the pelletizing process of a pelletizing machine to achieve densified biomass with the best quality, low energy consumption and high capacity. Also, determining the basic mechanism of the pelletizing process reduces design and production costs for manufacturing of the effective pelletizing machine. Nowadays, during experiments which are conducted on densification and pelletizing of biomass materials in a laboratory scale such as; investigation of the pelletizing process mechanisms, evaluation of effective parameters on the pelletizing process and modeling & simulation of the pelletizing process, generally simplified pelletizing apparatus are used (Fig. 3).

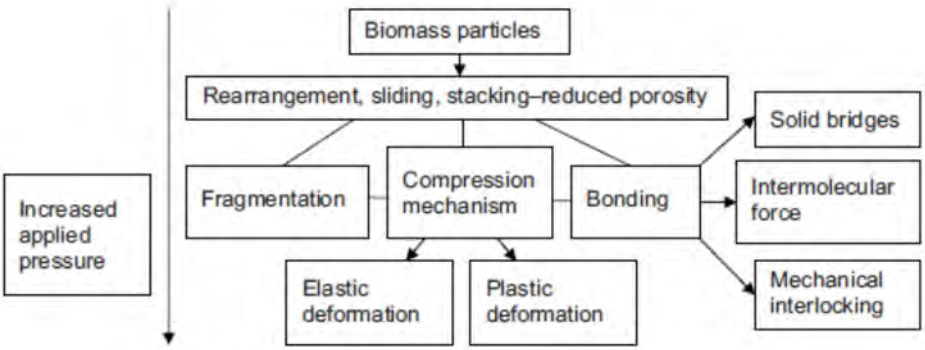

Figure 2. Compression Process Stages

Figure 3. Simplified Pelletizing Test Apparatus

Generally, a simplified pelletizing apparatus consist of a modified hydraulic press and a simplified pellet die. During this test method, a certain amount of biomass material is placed in the pellet die hole. In order to simulate the temperature resulting during actual pelletizing process, a heater and temperature settings system is placed around the pellet die. After temperature adjustment of a pellet die, the simulation period is started and the force required for pelletizing of biomass is applied by means of a hydraulic press plunger. During force application on the biomass sample, the movement rate of a plunger can be set in the range of 30 to 50 (mm/min). The application of the load on the biomass sample must be stopped, when the amount of force which is exerted on the biomass sample reaches the desired value. In this stage, the plunger position is fixed for 30 second. At the end of the process, the densified biomass sample is pushed out from the test apparatus (Adapa et al., 2006; Mani et al., 2006). By means of this experiment method, the reological properties related to biomass sample pelletizing such as, "force-displacement curve", "force- time curve" and "- strain curve", "density increase ratio" and ''durability'' of densified biomass can be introduced. Unfortunately, as the pelletizing process tests which are done by this method take place in a static condition, the studies carried out with this method can not present and simulate the real pelletizing process. Also, the currently used test method for the pelletizing study cannot describe multi-variable and compressive events like pelletizing and this simulation method is not sufficient for this purpose. Therefore, during the tests which are carried out with these apparatus the forces that occur during the pelletizing process could not be determined. So, in order to obtain complete data on the pelletizing process of biomass material and to measure the forces which occur between the pellet disk and rolls during pelletizing machine operation, a new type biomass pelletizing test device is required. The subjects of this study are to determine the handicaps of pelletizing tests which are carried out by means of the simplified pelletizing apparatus and introducing the requirement of a new pelletizing test system to obtain smooth data about biomass pelletizing and its design principles.

Objective and the scope

In order to evaluate the pelletizing process smoothly by means of a new type pelletizing test device, all the design points of an actual pelletizing machine must be considered in designing of the new type pelletizing test device. As it is known, the commercially manufactured pelletizing machines are consisting of a "feeding - conditioner unit", a "pellet die and its shaft", "pelletizing rolls and their shaft" and "power source and power transmission mechanisms" (Fig 4).

So, the new type pelletizing test machine must consist of all the parts of a real pelletizing machine. Also, in order to measure the forces which occur between a pellet die disk and rolls during pelletizing machine operation, force measurement systems must be installed (Whetstone Bridge witch are constructed by strain gauges) on proper parts of a machine.

A Pellet Die Disk System: The pellet die disk system consists of: a cylindrical disk with one row of holes on a circumference, a pellet disk carrier, a pellet disk shaft and its bearings. The diameters of holes which are located on the pellet die circumference and disk thickness must be adjustable. It can be done by using a pellet die with different thickness and different holes diameter. The pellet die disk is fixed to its carrier by means of a screw (Fig. 6).

Figure 4. Commercially Manufactured Pelletizing Machine

Pellet Roll Mechanisms: As it is mentioned, in order to evaluate pelletizing process correctly, the pelletizing test unit must be like a real pelletizing machine. Hence, a pellet rolls mechanism consists of two pelletizing rolls, a position adjustment system for rolls, a shaft of a pellet roll and a safety pin and its flange. This unit parts are illustrated in Figure 7.

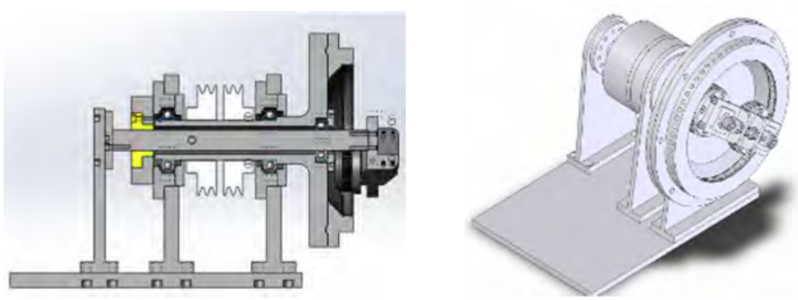

Figure 5. New Type Pelletizing Test Device

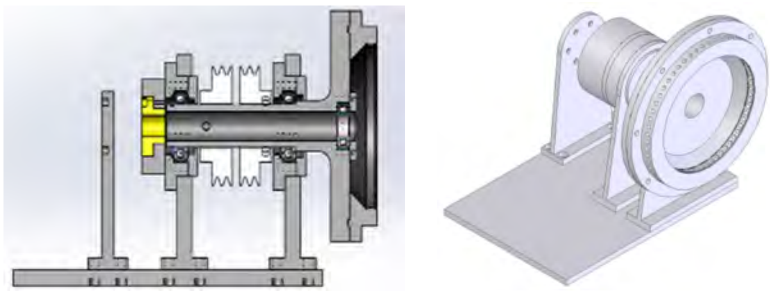

Figure 6. Pellet Die System and Its Equipments

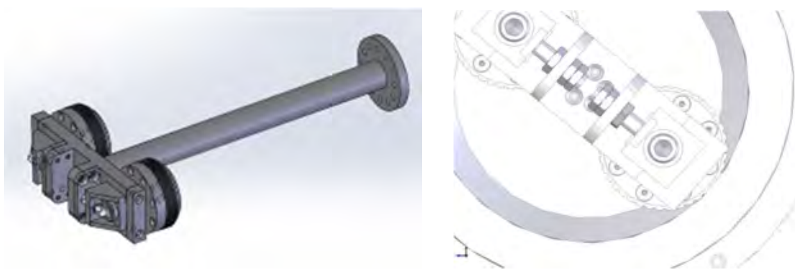

Figure 7. Pellet Rolls Mechanisms

As it is known, during pelletizing machine operation as a result of passing material between the rolls and a pelletizing disk, two types of forces are applied on rolls and a disk of a machine. These forces are defined as a pelletizing force and rolling resistance force (Fig. 8).

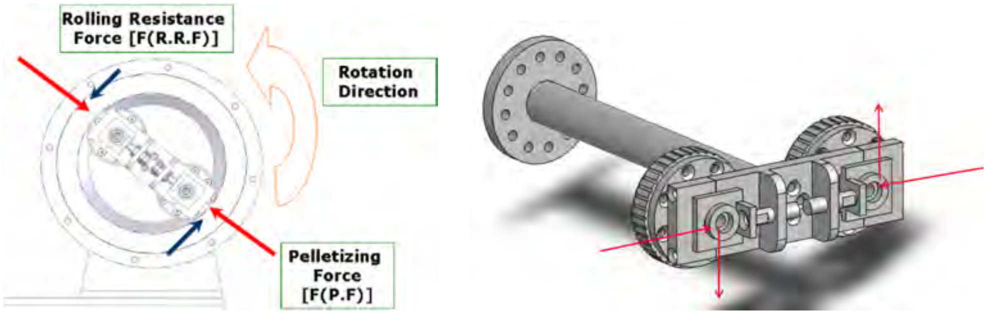

Figure 8. Forces Applied on Pelletizing Machine Parts

During traditional pelletizing test methods, these forces can not be measured correctly. In order to explain a real pelletizing process and to design different parts of a pelletizing machine, there is a demand to specify these forces. So, in this study to measure real values of pelletizing force and rolling resistance force which occur during the pelletizing process, proper whetstone bridges which are constructed by a strain gauge must be installed in a proper place of a pelletizing test device. In order to measure the pelletizing force data, it is necessary to install Whetstone Bridge in a proper place of a device where the only applied load is the pelletizing force. Therefore, a special design was used for the position adjustment mechanism of rolls. As, it is shown in Figure 9, the pelletizing force which occurred on rolls is transferred to position an adjustment screw where the only active load is a pelletizing load.

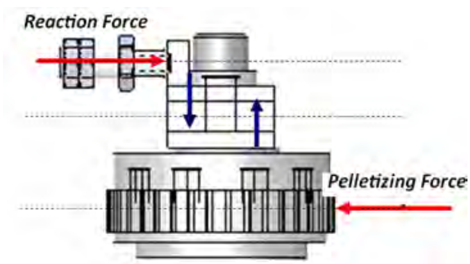

Figure 9. Forces on Position Adjustment Screw

As it was introduced above, the pelletizing force measurement can be actualized by installing a proper strain gauge construction as Whetstone Bridge for normal force measurements (Furman, 2006). The Whetstone Bridge construction belongs to normal force measurements is detailed in Figure 10.

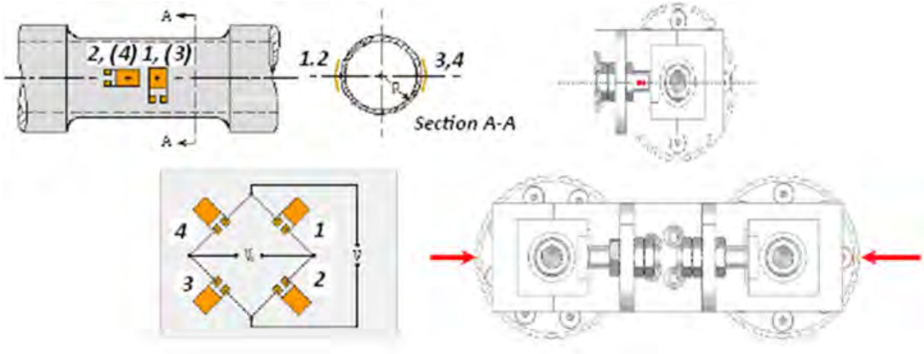

Figure 10. Construction of Whetstone Bridge for Measuring Pelletizing Force

Also, to obtain rolling resistance force data that occurs during pelletizing machine operation the proper whetstone bridge construction must be installed on a shaft of pellet rolls where the only active load is a torsion torque which arises from the rolling resistance force (Furman, 2006). The proper Whetstone Bridge construction for measurements of rolling resistance is illustrated in Figure 11.

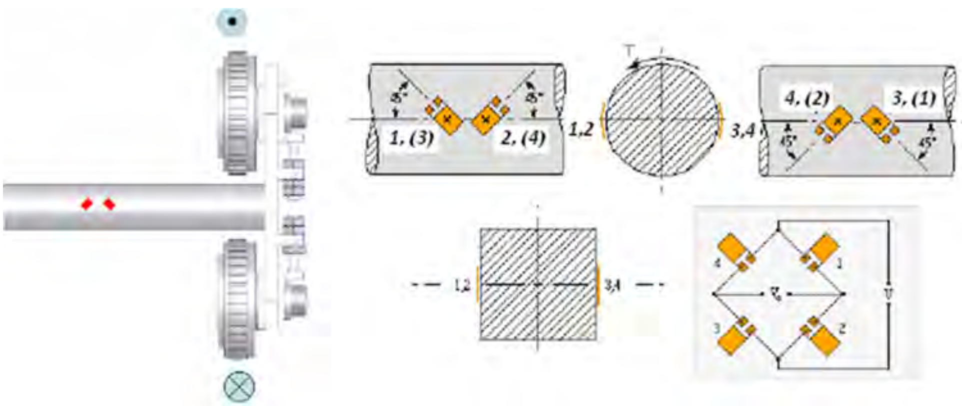

Figure 11. Construction of Whetstone Bridge for Measuring Rolling Resistance Force

Power Supply and Transmission Mechanisms: In order to simulate the pelletizing process actually, it is desired that all parts of a pelletizing test device look like a real pelletizing machine. Therefore, the new type pelletizing test device power supply source and power transmission system consists of two "AC" electro motors and belt drive mechanism. Also, in order to measure energy consumption, capacity and specific energy consumption data which is related to the pelletizing process, the new type pelletizing test device must be equipped with an energy analyzer device and a mass weighing system at the exit of a test device.

Conclusion

As a result of this paper, the pelletizing machines which are designed and constructed according to the data that is obtained from the new type pelletizing test machine will be the machines with high capacity and minimum energy consumption. By using the new type pelletizing test device which is introduced in this paper, the real pelletizing characterization of any kind of agricultural residues like olive cake, cotton stalks and corn stover can be determined. Therefore, these types of agricultural residues will be evaluated as high value-added materials. The use of the new type pelletizing test device will lead the researchers to obtain optimum values of parameters which affect the pelletizing process of any kinds of biomass material. Collection of these data can cause formation of the biomass pelletizing data base. As it was mentioned above, the pelletizing machines which are manufactured according to the data that are achieved from the new type pelletizing device will have high efficiency energy consumption. Therefore, the pellets which are produced by means of these machines will have low cost and economical price, and it means low price of energy. One of the most important results of this study is determination of the data of pelletizing and rolling resistance forces. These data are critical data with regard to design and mechanical analysis of different parts of pelletizing test machines. The use of the new type pelletizing test device by researchers will result in determination of the basic mechanism of the pelletizing process which reduces the design and production costs of the effective pelletizing machine.

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ZAPOTRZEBOWANIE NA NOWE URZĄDZENIE TESTOWE DO PELETYZACJI BIOMASY

Streszczenie. Ponieważ gęstość nasypowa biomasy jest niska, pojawiają się problemy podczas przechowywania, transportu i użytkowania biomasy. W celu pokonania tych problemów należy zastosować proces zagęszczenia by zwiększyć gęstość nasypową biomasy. Charakterystyka biomasy ulega poprawie, zwiększa się objętościowa wartość opałowa biomasy, koszty jej przechowania zostają zmniejszone a charakterystyka spalania biomasy poprawia się dzięki procesowi zagęszczenia. Obecnie, peleciarki mają szerokie zastosowanie w zagęszczaniu biomasy. Podczas pracy maszyny peletującej, osiągnięcie wysokiej jakości sprasowanej biomasy przy wysokiej wydajności i niskim zużyciu energii jest ściśle związane z kryteriami projektowania maszyny peletującej. Zatem, konieczne jest zbadanie parametrów, które wpływają na działanie maszyny peletującej. Na skale laboratoryjną, badania związane z peletyzacją i zagęszczaniem biomasy są prowadzone za pomocą uproszczonego aparatu peletyzującego. Niestety, badania, które prowadzone są za pomocą tej aparatury z powodu zasad jej działania nie mogą całkowicie zilustrować procesu peletyzacji i sił występujących podczas tego procesu. Ponieważ obecne systemy wykorzystywane w procesie peletyzcaji są niewystarczające, by wyjaśnić, wymodelować i zoptymizować proces peletyzacji w sposób bardziej skuteczny oraz by osiągnąć wiarygodne dane dla projektu maszyny peletującej, konieczne jest stworzenie nowej aparatury. Niniejsza praca wyjaśnia potrzebę stworzenia nowego urządzenia testowego do peletowania biomasy.

Słowa kluczowe: biomasa, paletyzacja, badania laboratoryjne, peletujące urządzenie testowe

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IMPACT OF UV-C RADIATION ON THE INFESTATION DEGREE OF THE STORED POTATO TUBERS WITH *RHIZOCTONIA SOLANI* KÜHN

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ABSTRACT

Within 2012-2014 two independent storage experiments aiming at determination of the UV-C radiation impact on the infestation degree of potato tubers with *Rhizoctonia solani* Kühn were carried out. Potato tubers were radiated in the chamber equipped with a UV-V 15 radiator located over the bottom of a chamber from 0.4 to 1.0 m over the ground using the exposition time within 1 to 60 minutes. Four edible potato varieties with a varied degree of earliness and varied fitness for use and culinary utility of the following tubers: Lord, Owacja, Vineta and Jelly, were used in tests. It was determined that radiation of Owacja tubers before storing caused reduction of Rhizoctonia canker in comparison to the control sample.

Introduction

Losses caused by pathogenic micro-organisms are one of the reasons why potato tubers are affected by mass reduction when stored. A disease, which often occurs on potato plants in all stages of their growth is Rhizoctonia canker caused by fungi from the species of *Rhizoctonia solani* Kühn (a perfect stadium *Thanathephorus cucumeris*). These fungi are responsible for decay of seed potato sprouts, rotting of stem bases, pock-marking of tubers and they are the source of a daughter plant infection (Van Emden, 1965; Lehtonen et al., 2008ab, Jakubowski, 2010). Pock-marking is one of the disease forms which occur on the potato tuber skin. Infected tubers are covered with dark sclerotium (a surviving form of a pathogen), which are formed when potato matures; after harvesting they remain on the tuber periderm during the storage period. Main agrotechnical methods of fighting with Rhizoctonia canker include chemical treatment of seed potatoes and protection of a plantation with the use of fungicide preparations. However, it should be emphasised that such methods of plant protection against this pathogen are not recommended in case of organic crops (Lenc, 2006). The use of physical methods, with regard to the stored potato tubers, is a solution which includes rigorous requirements of organic agriculture. Results of the research carried out by Martens et al. (1992) and Castro et al. (1993) indicate that the pulse electric field effect on *Saccharomyces cerevisiae* fungi reduces their population. Similar effects were obtained by Marks (2005ab), who investigated the impact of the pulse electric field and variable magnetic field on *Alternaria solani* fungi growth in the stored potato tubers of Drop, Irga and Salto potato tubers. Results of the research carried out by the same author (Marks et al., 2005c; 2006) prove that both effect of the electric field as well as the magnetic one and microwave radiation (Jakubowski, 2010) decreases storage losses of potato tubers of Drop, Irga, Salto, Felka Bona, Rosara and Velox varieties caused by Rhizoctonia canker. The results presented above show efficiency of the effect of the mentioned physical methods on some pathogens of potato tubers. Therefore, searching for and investigating the impact of many physical methods, which limit development of storage diseases of potato, is reasonable.

Ultraviolet radiation is one of the components of the solar spectrum, which reaches the Earth. Ultraviolet (UV) in relation to the wave length and effects on living organisms occurs in three bands (scopes): UV-A (315-400 nm), UV-B (280-315 nm), UV-C (100-280 nm). In spectroscopy, division of radiation is slightly extended: border, far, medium and close (respectively: 10-121, 122-200, 201-300, 301-400 nm). It should be emphasised that the above mentioned divisions (scopes) are of contractual nature (Lucas et al., 2006).

Impact of ultraviolet radiation on the biological material (soy August variety) was the subject of the research carried out by Szwarc and Skórska (2007). The applied UV-B radiation reduced intensity of photosynthesis, the content of chlorophyll and negatively influenced the increase and biomass of overground parts. Defence reactions in the form of the increased synthesis of flavonoids and increased acitvity of antioxidizing enzymes (peroxidase and catalase) were reported. UV radiation in C band was used in the processes of food sterilization (Corales, 2012) namely as a method of plant protection (patent US 2009/0272029 A1). Páez et al. (2011) used a physical method for fighting with seeds mycobiots and Korobczak et al. (2005) used radiation of potato plants with UV-C in order to cause the symptoms of abiotic stress. Błażejak et al. (2011) carried out research on the use of ultraviolet radiation for obtaining mutants *Gluconacetobacter xylinus*, which were then used to carry out biotransformation of glycerol in DHA (the best of mutants synthesized 18.00 mg $DHA \cdot cm^{-3}$, that is by 32% of $DHA \cdot cm^{-3}$ more than the parent graft). With reference to potato, the impact of UV-C radiation was investigated in the aspect of its impact on seed potatoes of Jelly variety and the further course of plant ontogenesis (Jakubowski and Pytlowski, 2013). A significant impact of radiation became visible in the development of the overground part of potato. Taking into consideration the above, the objective of the experiments, which were carried out, was to determine the impact of UVC radiation on the infestation degree of the stored potato tubers with *Rhizoctonia solani* Kühn.

The scope of paper and methodology of research

Within 2012-2014 two independent storage experiments aiming at determination of the UV-C radiation impact on the infestation degree of potato tubers with *Rhizoctonia solani* Kühn were carried out. The experiment differentiated the origin of material for research and the used potato variety. The common feature of experiments was the use of potato tubers as a material for research and the use of UV-C radiation towards the material. Four edible potato varieties with a varied degree of earliness and varied usefulness and culinary utility of tubers were used in the experiment: Lord (a very early variety useful for production of canned food, vegetable salads and frozen products, hard), Owacja (an early variety, of general usefulness, slightly hard and floury), Vineta (an early variety useful for production of canned food, vegetable salads and frozen products, hard) Vineta (an early variety, useful for production of canned food, vegetable salads and frozen products, hard) and Jelly (a middle late variety, of general utility, slighlty hard). Degree of infestation with *Rhizoctonia solani* Kühn was determined through a percentage of infestation with sclerotium (pock-marking) of the potato tuber periderm acc. to methodology of IHiAR [Plant Breeding and Acclimatization Institute] (Roztropowicz, 1999). Infestation was determined through the reverse scale 9º (9º – not infected, 1º – infestation above 25% of the skin surface). Potato tubers were radiated in a chamber equipped with TUV UV-C 15 W type radiator (intensity of linear radiation 253.7 nm in the distance of 1 m from the lamp – 0.42 $W \cdot m^{-2}$, total linear energy stream 253.7 nm=4.0 W) located over the bottom of the chamber at the height of 0.4 to 1.0 m using the exposition time within 1 to 60 minutes. (table 1). In the experiment no. I material for research came from a crop under the plastic tunnel. The methodology of agrotechnological treatments and the arrangement of experiment was the same as the one presented in the author's paper concerning the impact of ultraviolet on the growth and yield of potato plant (Jakubowski and Pytlowski, 2013). Experiment (no. I) provided for radiation of tubers before planting, evaluation of the infestation degree with rhizoctonia canker directly after harvesting and after storing. In experiment no. II the research material came from field cultivations, where correct rules of agrotechnology designed for potato plants were applied. Experiment (no. II) provided for the evaluation of the infestation degree of potato tubers with rhizoctonia canker directly after the harvest of yield, radiation of tubers before their storing and then another evaluation of infestation after storing. In both experiments in the subsequent years of the research, a possibility of modification of working parameters of a chamber within the scope of the exposition time and the height of a radiator was taken into account. Combinations in experiments included a control sample. The obtained results were subjected to statistical interpretation with the use of STATISTCA 10 at the level of significance $\alpha=0.05$. The analysis of variance preceded by the research on the regularity of the distribution in samples (Kolmogorov-Smirnov test) and the uniformity of variance (Levene's test) was carried out. Multiple comparisons were made with the use of Duncan's range test based on the order statistics. On account of different origin of the research material and the admitted possibility of modification of working parameters of the chamber, no statistical differences between the years and experiments were determined.

Table 1
Arrangement of experiments within 2012-2014

Symbol of experiment		Year of realization	Characteristics of experiment				
			Variety	Sample size (items) in combination (for variety)	Time of radiation (min)	Height of radiator (m)	Date of radiation
I	A	2012-2013	Jelly	30(120)	0*, 1, 10, 60	0.7	before planting
	B	2013-2014			0*, 5, 15, 30	0.4	
II	A	2012-2013	Lord Owacja Vineta	100(1000)	0*, 1, 10, 30	0.4, 0.7, 1.0	before storing
	B	2013-2014	Owacja	100(500)	0*, 15, 20	0.5, 0.6	

*control sample

Research results and discussion

Results of Kolmogorov-Smirnov test proved compliance of the empirical distribution of samples with a regular distribution. Levene's test confirmed uniformity of variance in the investigated samples. The above test authorized the use of a multi-factor analysis of variance including interaction effects. In all the researched combinations of the experiment a higher degree of infestation of potato tubers with rhizoctonia canker after storing compared to evaluation made before placing them in a freezer was determined.

In case of experiment no. I, where material from cultivation under plastic foil with reference to the control sample, no statistically significant impact of radiation of seed potatoes on the degree of infestation of the stored potato tubers with rhizoctonia was reported (insignificant value of Snedecor's test F=3.45). In experiment no. Ia 10 min. – radiation time, compared to the control, caused decrease of the infestation degree with rhizoctonia by average 2.2%. In experiment IB the height of a radiator and time of its operation was corrected. The effect of changes of the chamber operation parameters was reflected in a lower degree of infestation with rhizoctonia (by average 2.5%) at the radiation time of 15 minutes. (referred to the control sample).

In the part of the experiment (no.II), where the research material came from field cultivations, a significant impact of quality predictors, accepted in the experiment, on the investigated dependable variables was presented (Table 2). Post-hoc tests which were carried out in the experiment IIA proved that, Owacja variety reacted positively (table 3 and 4) on 10 minute UV-C radiation at the height of a radiator of 0.4 and 0.7 m (a lower by 5.5%, degree of infestation of radiated tubers, at the average for both heights of a radiator, in comparison to the control sample was reported).

In experiment IIB (where Owacja variety was investigated) the height of a radiator and the time of its operation were corrected which resulted in a significantly lower degree of infestation with rhizoctonia (average by 5.3%) at 15 min. radiation (with reference to the control sample). In this part of the experiment, it was not confirmed that the height of a radiator significantly influenced the degree of potato tubers infestation with rhizoctonia (table 4 and 5).

Table 2

Results of analysis of variance for part of experiment IIA; impact of variety, UV-C radiation time and height of radiator on degree of tubers infestation with rhizoctonia after storing

Quality predictor	Sum of squares	Number of degrees of freedom	Mean square	Value	
				of F Snedecor test	of test probability
Absolute term		0			
Variety	39.92	2	19.96	15.23	0.000
Time	32.98	2	16.49	12.59	0.000
Height	21.61	2	10.80	8.25	0.001
Error	382.48	2994	0.13		

Table 3

Arrangement of variable homogeneous groups; reaction of investigated potato varieties radiated by UV-C on degree of tubers infestation with rhizoctonia (after storing)

Variety	Degree of infestation	Homogeneous groups	
		1	**2**
Lord control	7.6	****	
Lord	7.6	****	
Owacja control	7.8	****	
Vineta control	7.8	****	
Vineta	7.8	****	
Owacja	8.3		****

Table 4

Results of analysis of variance for part of experiment IIB; impact of variety and height of radiator on degree of Owacja tubers infection with rhizoctonia after storing

Quality predictor	Sum of squares	Number of degrees of freedom	Mean square	Value	
				of F Snedecor test	of test probability
Absolute term		0			
Time	6.40	1	6.40	9.50	0.003
Height	2.50	1	2.50	3.71	0.061
Error	31.00	498	0.06		

Table 5

System of variable homogeneous groups; impact of radiation time on degree of infestation with Rhizoctonia canker of Owacja variety tubers after storing

Time of radiation	Degree of infestation	Homogeneous groups	
		1	**2**
Control	7.6	****	
20 min	7.7	****	****
15 min	8.0		****

Here it should be emphasized that although the value of Snedecor's test (F=3.71), which determined the effect of the grouping variable (the radiator height) on the infestation with rhizoctonia proved to be insignificant (p=0.0603), the value of the test probability is very close to the border value of the assumed level of significance α. The results obtained within 20 minutes of radiation time, may be interpreted explicitly since the so-called "group overlapping" takes place.

The result of the experiments, reserving the variability of the origin source of the material for research, allows formulation of general statements:

- the time of UV-C radiation with is significant (before planting, before storing),
- the reaction of plants to UV-C radiation may be a varietal property,
- it is possible that the effect of interaction between the UV-C radiation time and the height of a radiator over the bottom of a chamber is crucial.

According to Pilarski et al. (2012) a solar spectrum which reached the surface of the Earth's atmosphere covers a very broad spectrum of radiation (from several hundred to several thousand nm). This radiation, when it is getting through atmosphere, is absorbed and dispersed as a result of reaction with atoms, particles, aerosols and dust (natural and anthropogenic ones) included therein. Molecular oxygen, as well as in the atomic form or in the form of ozone, absorbs ultraviolet radiation which results in the changes of a spectrum, which gets to the Earth surface. The spectrum is devoid of almost entire UV-C and UV-B radiation and includes insignificant amounts within UV-A. The above shows that UV-C radiation, used for the needs of agricultural demands, may be produced in principle exclusively by artificial sources. The plant produced in itself protecting mechanisms against harmful effect of UV. This role is played by flavonoids (flavonols and anthocyanins) which reduce UV radiation transmission through epidermis at the simultaneous permeability of PAR radiation. The effect of screening is protection of a photosynthetic apparatus and plant structures against DNA damages. Moreover, a protective role is played by various epidermis forms, e.g. hair may disperse up to 70% of the UV radiation. Pigments (except for flavonoids) which protect against harmful UV effect are carotenoids which have anti-oxidizing properties and which extinct active form of oxygen (Tevini, 1993; Robin et al., 1994; Cockeel et al., 1999; Pilarski et al. 2012).

Radiation in UV-C band consists in waves with the length of 100-280 nm. Waves with length of 100-200 nm, the so-called Shumann's rays, are not biologically active because they are absorpbed by oxygen and particles of water steam. This limitation causes that biologically active ultraviolet in C band is represented by waves with length of 200-280 nm but the highest activity is within the range of 250-270 nm (254 nm). This information is crucial because when the experiment is carried out, it allows narrowing the research scope in the described object. In the available literature no information on the possibility of absorption (as well as adsorption) of UV radiation by potato tubers was found out. On this stage of research, it may be assumed that in case of plant material a similar mechanism of assimilation of electromagnetic wave as the one described in physiotherapy issues may occur (Poon et al., 2005). Therefore, it shall be assumed that radiation within 184.9-290 nm (the scope applied in phototherapy) gets through a potato tuber up to the depth of 2 mm (namely as deep as periderm and pith which adheres to it). Moreover, the radiated object must comply to Grotthuss-Draper's law according to which a photochemical transformation in the reacting system may be caused only by radiation absorbed by this system (Lechowski and Białczyk, 2003; Negash and Björn, 1986; Worrest and Häder, 1997). Effect of ultraviolet on biological material causes a photochemical reaction (photosynthesis, photolysis, oxidization and reduction).

From the point of view of the researches which were carried out, a photochemical effect in the form of photoisomeration seems to be significant. This reaction in case of a potato tuber, consist in transformation of chemical compounds (organic pigments as flavonoids) into its another isomer as a result of photons effect (Reddivari et. al., 2007; Keutgen et al., 2014). Although isomers are chemical compounds with identical total molecular formulas, as compounds they were built of, they differ with order and manner of atomic bonds as well as they may be distributed differently. The above discussions should be assumed as hypothetical and treated as a presumption to carry out further research in this field. A reasonable justification of the obtained research result (reduction of the degree of infestation with rhizoctonia) is accepting a biophysical nature of the phenomenon in the form of UV-C radiation effect on the biological material. UV-C radiation with the wave length 253.7 nm has sterilizing and disinfecting properties. This effect is visible in particular when referred to bacteria, viruses and fungi through the effect which leads to DNA chains damages (Kowalski, 2009). It is probable that potato periderm exposition to ultraviolet in C band may reduce *Rhizoctonia Solani* Kühn fungi population and thus reduce the pock-marking of tubers caused by them.

Conclusions

1. No significant impact of radiation of seed potatoes before their planting on the degree of infestation of potato tubers with rhizoctonia canker before their storing was reported (experiment with symbols IA and IB).
2. From among the investigated potato tubers, only Owacja variety reacted positively with lower infestation with rhizoctonia of the stored tubers on UV-C radiation (experiment with symbols IIA and IIB).

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WPŁYW PROMIENIOWANIA UV-C NA STOPIEŃ PORAŻENIA PRZECHOWYWANYCH BULW ZIEMNIAKA PRZEZ *RHIZOCTONIA SOLANI* KÜHN

Streszczenie. W latach 2012-2014 przeprowadzono dwa niezależne doświadczenia przechowalnicze mające na celu określenie wpływu promieniowania UV-C na stopień zainfekowania bulw ziemniaka przez *Rhizoctonia solani* Kühn. Bulwy ziemniaka naświetlano w komorze wyposażonej w promiennik UV-C 15 W usytuowany nad dnem komory na wysokości od 0,4 do 1,0 m stosując czas ekspozycji w zakresie od 1 do 60 min. Jako materiału do badań użyto czterech jadalnych odmian ziemniaka o różnym stopniu wczesności oraz różnej przydatności użytkowej i kulinarnej bulw: Lord, Owacja, Vineta i Jelly. Stwierdzono, iż naświetlanie przed przechowywaniem bulw odmiany Owacja przyczyniło się do zmniejszenia porażenia rizoktoniozą w porównaniu z próbą kontrolną.

Słowa kluczowe: ziemniak, przechowywanie, rizoktonioza, UV-C

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EVALUATION OF THE IMPACT OF PRE-SOWING MICROWAVE STIMULATION OF BEAN SEEDS ON THE GERMINATION PROCESS

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ABSTRACT

The objective of the paper was to evaluate the impact of microwave stimulation of bean seeds on their germination process. Laboratory tests were carried out in 2012-2014 with the use of certified bean seeds (*Phaseolus vulgaris* L.) of Igołomska cultivar. Shortly before sowing, bean seeds were radiated with microwaves for 10, 30 and 60 seconds. Microwaves came from a magnetron which operated with 100 W power and produced waves of 2.45 GHz frequency. The germination process was described and parameters, which define the sowing value of bean seeds, were determined. Germination ability, relative germination ability (Maguier's index) and average germination time (Pieper's index). Fresh and then dry mass of plant mass were determined. The obtained results allow the statement that microwaves modify the germination process of bean seeds.

The list of abbreviations and symbols:

M_f – mass of a single bean seed, (g)
φ_f – coefficient of shape of a single bean seed, (-)
Pb – water volume of tissue paper, (-)
Sn – degree of water saturation of a germination bed, (Sn = 0.5 to 1.0) (-)
Mb – mass of tissue paper in the germination box, (g)
$Ś_{mf}$ – fresh mass of a bean plant, (g)
S_{mf} – dry mass of a bean plant, (g)
U_{mf} – mass loss of a bean plant, (g)
Wz – coefficient of variation, (%)
Sd – standard deviation,
min., max., average – respectively: maximum value, minimum value and average
l – number of germinated seeds in subsequent days of observation,
d – number of a day from seeds dissemination,
η_p^2 – (partial eta square) measure of size of experimental effects.

Introduction

Health of seeds is one of fundamental properties which prove its quality and usefulness in agriculture. Next to treating seeds with crop protection chemicals or immersion in chemical solutions also physical methods of their disinfection are applied (removing part of a seed cover habited by pathogens, thermal activity, the use of electromagnetic or mechanical waves of varied frequency) (Ispir and Togrul, 2009; Kaniewska et al., 2012). On account of legal regulations of the European Parliament concerning introduction (restrictions) of crop protection chemicals to turnover (Regulation EP 1107, 2009) it is recommended to search for seeds disinfection methods which are new and at the same time such that do not deteriorate the germination vigour. Bean seeds, on account of the content of polyphenols are antioxidant (a functional property) (Drużyńska and Klepacka, 2004). At the same time Chmielowiec and Borowy (2004) emphasise that Poland is the third producer of dry bean seeds in Europe and in the recent years in our country, bean cultivation for dry seeds was approximately 20 thousand hectares (Łabuda, 2010). According to Villavicencio et al. (2000) bean seeds are one of the main sources of protein in a diet in developing countries. Cultivation of beans poses also some difficulties and one of them is obtaining fast and high crops, since in the period from sowing to germination, seeds are exposed to decay caused by the pathogens activity (Szafirowska and Kołosowski, 2008). Both seeds as well as young seedlings may be the place where pests live (e.g. Hylemyia florilega Zett., Delia platura Meig). Participation of seeds in the mass of a whole plant along with its maturation of stems, decreases. Approximately 24-55% of the total dry mass of bean plants is stored in bean pods (Halepyati and Ali, 1993). Undoubtedly, physical methods of its protection are an alternative for chemicalization of seeds. Refining seeds should not only increase its vigour or limit variability of physical and chemical properties but also favourably affect the growth and development of a plant in further stages of its ontogenetic development (Wójcik et al., 2004). Radiation of seeds with microwaves is one of physical methods of stimulation of seeds (Olchowik et al., 2002). In the world scientific literature results of research concerning a positive influence of microwaves on lentil seeds (Aladjadjiyan, 2010), rapeseed (Oprică, 2008) and soya, wheat, barley and oats (Reddy et al.,1995, 1998; Yoshida et al., 2000; Ponomarev et al. 1996) were discussed. The research carried out by Tylkowska et al. (2010) shows that microwave radiation (with the frequency of 650 W and 2450 MHz) used with reference to bean seeds (*Phaseolus vulgaris*) of Laurina cultivar limited occurrence of *Penicillium* spp.fungi, both on the surface as well as outside seeds. Similarly Friesen et al. (2014) stated that radiation of bean seeds (*Phaseolus vulgaris*) of Navigator and Ole cultivars with microwaves (1100 W and 2450 MHz) reduces infection of plants with *Colletotrichum lindemuthianum* (which causes bean anthracnose). In the research, which was presented above, it was not found out whether microwaves modify the germination process of bean seeds. The author's research (Jakubowski, 2010a) concerning the effect of microwaves (100 W and 2450 MHz) on potato plants indicate that radiation of the bulb affects the process of its germination at the simultaneous decrease of the degree of infection with canker (Jakubowski, 2010b). Thus, there is a probability that microwave radiation of bean seeds with 2450 MHz frequency generated by a magnetron operating at 100 W power, will modify the process of plant germination. The objective of the paper was to evaluate the impact of microwave stimulation of bean seeds on the germination process.

The scope of paper and the methodology of research

Laboratory tests were carried out in 2012-2014 with the use of certified bean seeds (*Phaseolus vulgaris* L.) of Igołomska cultivar. It is a prolific very early variety with white averaged size seeds. Sowing is performed the most often in May and June (in a greenhouse cultivation it may be as early as in April). Material for tests was obtained from Krakowska Hodowla i Nasiennictwo Ogrodnicze POLAN Spółka z o.o.

$$\varphi = \sqrt[3]{\frac{a \cdot b \cdot c}{c^3}} \quad (1)$$

In order to present the uniformity of the research material, mass (M_f) and the coefficient of shape (φ_f) of a single bean seed (acc. to formula 1) was determined. The mass was determined with the use of a laboratory balance (Radwag XA 110/X, d=0.01 g) and dimensions of seeds with the use of a caliper (DIN 862 +/– 0.03 mm) coupled with a data registration unit (measurement). Each combination of the experiment included 3 replications. The experiment included investigation of differences between replications within each combination and then differences between combinations. It was assumed after Anders (2003) that replication is sufficient when it meets the following conditions: values of the coefficient of variation W_z for variables M_f i φ_f will not exceed respectively 10 and 15% (Table 1) and the distribution of the investigated separation property showed the properties of regular distribution (or logarythmic – regular). From the point of view of methodology, this manner of selection of a sample was indicated because Lima et al. (2005) proved relations between the size of a bean seed and its growth, development and cropping. Adjusting empirical distribution of the sample to the regular theoretical distribution (logarythms-regular) was carried out with Kolmogorov-Smirnov test. Shortly before sowing, bean seeds, placed on the petri dish were radiated with microwaves for 10, 30 and 60 seconds. Microwaves came from a magnetron which operated with 100 W power and produced waves of 2.45 GHz frequency. In order to determine energy absorbed by a single bean seed during microwave radiation a unit dose of microwave radiation was calculated (the amount of the total dose of microwave radiation and the mass of bean seeds. The total dose of microwave radiation was defined as the power product of a device which generates microwaves and the exposition time. After irradiation, seeds were placed in plastic containers which serve as a germination apparatus. On the bottom of each germination apparatus a layer of lignin was placed (M_b), which was moistened with water (M_w). According to the relation (2) in the initial phase of experiment, the degree of water saturation of lignin (S_n) equal to 0.8 was obtained (Domoradzki, 1999).

$$M_w = P_b \cdot M_b \cdot S_n \quad (2)$$

In the so prepared germination apparatus, seeds were placed, which were later left without light for 48 hours in temperature of 22ºC. For the following 8 days, seeds were germinated with daylight in temperature of 20-22ºC. Each day (according to PN-R-65950: 1994 and ISTA standards the number of seeds with a growing germinal root, which pierced all coats, actively elongates and geothropically curves was determined – a visible primary root or hypocotyl) and water in germination apparatuses was regularly filled up. Total period of time of the experiment (initial sprouting germination) was selected to include three basic stages of germination (imbibition stage (2 days) and catabolic and anabolic stage (remaining 8 days). The process of germination was presented graphically and the following parameters were determined (Gładyszewska, 2004; Binek and Moś, 1984) which define the sowing value of bean seeds:

- germination ability of the investigated bean seeds was defined as a percentage of normally germinated seeds within the standard time,
- Maguier's index (W_{Magu}) which determines a relative germination speed (3),

$$W_{Magu} = \frac{l1}{d1} + \frac{l2}{d2} + \cdots + \frac{ln}{dn} \tag{3}$$

- Pieper's index (W_{Piep}) which determines average time of germination of a single bean seed (4).

$$W_{Piep} = \frac{(l1 \cdot d1 + l2 \cdot d2 + \cdots ln \cdot dn)}{(l1 + l2 + \cdots + \mathrm{ln})} \tag{4}$$

On the tenth day, germinated seeds were taken out of germination apparatuses along with roots and the fresh and then dry mass of plants was determined. In order to determine fresh mass ($Ś_{mf}$) strained plants were weighted one by one on a laboratory balance (Radwag XA 110/X, d=0.01 g). In order to determine dry mass of plants (S_{mf}) samples were dried in temperature of 105°C in a laboratory drier for 5 hours and then their weight was determined (analogically to the description above). The loss of plants mass (U_{mf}) resulting from drying was determined as a difference $\sum Ś_{mf}$ and S_{mf}.

Table 1
Values of basic statistics for the used experimental material (example for 2012)

Radiation time	Replication no.	Mass (g)					Coefficient of shape				
		min	*max*	*aver.*	*Sd*	*Wz*	*min*	*max*	*aver.*	*Sd*	*Wz*
0 s (control)	1	0.37	0.45	0.41	0.04	10.0	0.630	0.639	0.634	0.091	14.3
	2	0.38	0.44	0.41	0.03	7.5	0.631	0.647	0.639	0.072	11.3
	3	0.38	0.45	0.41	0.04	10.0	0.629	0.641	0.635	0.059	9.3
10 s	1	0.37	0.45	0.41	0.04	9.5	0.627	0.648	0.637	0.058	9.1
	2	0.39	0.45	0.42	0.03	7.7	0.628	0.629	0.628	0.076	12.1
	3	0.37	0.45	0.41	0.04	10.0	0.619	0.647	0.633	0.088	13.9
30 s	1	0.37	0.45	0.41	0.04	9.5	0.617	0.644	0.630	0.082	13.0
	2	0.39	0.45	0.42	0.02	5.1	0.621	0.645	0.633	0.066	10.4
	3	0.38	0.45	0.41	0.03	7.3	0.623	0.648	0.635	0.089	14.0
60 s	1	0.37	0.45	0.41	0.03	6.3	0.628	0.654	0.641	0.064	9.9
	2	0.39	0.45	0.42	0.03	7.0	0.616	0.640	0.628	0.073	11.6
	3	0.37	0.44	0.41	0.04	9.8	0.622	0.645	0.633	0.071	11.2

The research results were analysed with the use of *STATISTICA 10* software on the assumed significance level of α=0.05. In the selected sources of variation, components of variation were assumed according to the mixed model, where the time of microwave radiation (along with the control sample) was assumed as a constant factor and years of research were a random factor. Normality of distribution was determined in samples with Kolmogorov-Smirnov's test and the uniformity of variation with Levene's test. Significance of differences was investigated with the analysis of variance with the use of *F*–Snedecor's test.

Additionally, the value of Wilks' test was provided and the measure of effects size (η_p^2 was calculated – proportion of the error variation and effect explained by the effect) for the analysis of variance which was carried out. On account of the specificity of experiment (possible lack of equipotency in tests in the final stage of experiment) for multiple comparisons the Spjotvoll and Stoline's procedure was used (generalization of *HSD* Tukey's test).

Results of the experiment and discussion

Value of the coefficient of variance in samples for a variable M_f, was within 7.2-10% and for a variable φ_f within 9.1-14.3% in the first year of experiment (Table 1) in subsequent years of research analogically: M_f 7.8-10%, φ_f 11.4-14.1% and M_f 8.4-9.9%, φ_f 12.3-14.8%. Calculated values of Kolmogorov-Smirnov's statistics were insignificant (on the assumed level of α=0.05), which means that samples accepted for the research fitted with its empirical distribution into the standard regular distribution. Doses of microwaves which were used to radiate bean seeds were within (average for the period of research): respectively for the exposition (10 s) 2.38-2.44 $kJ \cdot g^{-1}$, (30 s) 6.98-7.50 $kJ \cdot g^{-1}$ and (60 s) 13.95-14.63 $kJ \cdot g^{-1}$. After the process of germination, between replications within the combination (in a given year when the experiment was carried out) no significant differences in the values of the investigated dependent variable (fresh mass) were reported. The analysis of variance, which was carried out, showed a significant impact of quality predictors on the investigated dependent variables (Table 2). In the next step, for statistically significant grouping variables, post-hoc tests were carried out (Tables 3-5). Due to the fact that all years of research differed significantly, further analysis (post-hoc tests) was carried out as a one-factor (treating individually each year of experiment).

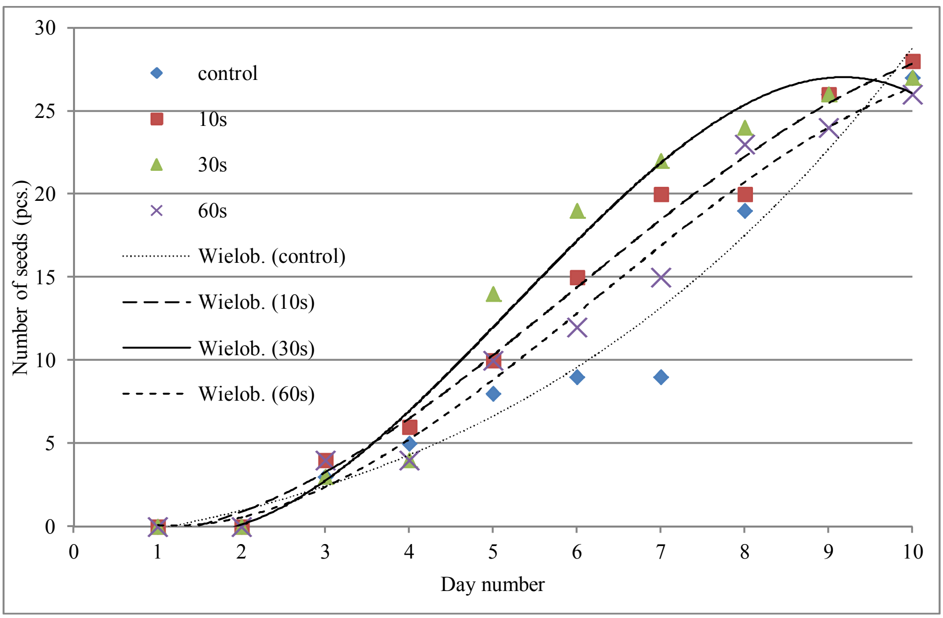

Figure 1. Number of bean seeds which germinate correctly in particular days (example for 2012)

The investigated process of germination of bean seeds, described by the number of seeds which correctly germinate (fig. 1) is characteristic for the plants of a species used in the experiment (Kornarzyński and Pietruszewski, 2008) and arranges acc. to a characteristic sigmoidal curve. In each year of research it was found out that the highest germination ability was in case of bean plants which grew out of seeds, which were radiated with microwaves for 10 s and the lowest radiation for 60 s. Bean plants which grew out of seeds, which were radiated for 10 s had a germination ability higher by 2.2% in 2012, 1.3% in 2013 and 2.5 % in 2014 in comparison to the control sample (fig. 2).

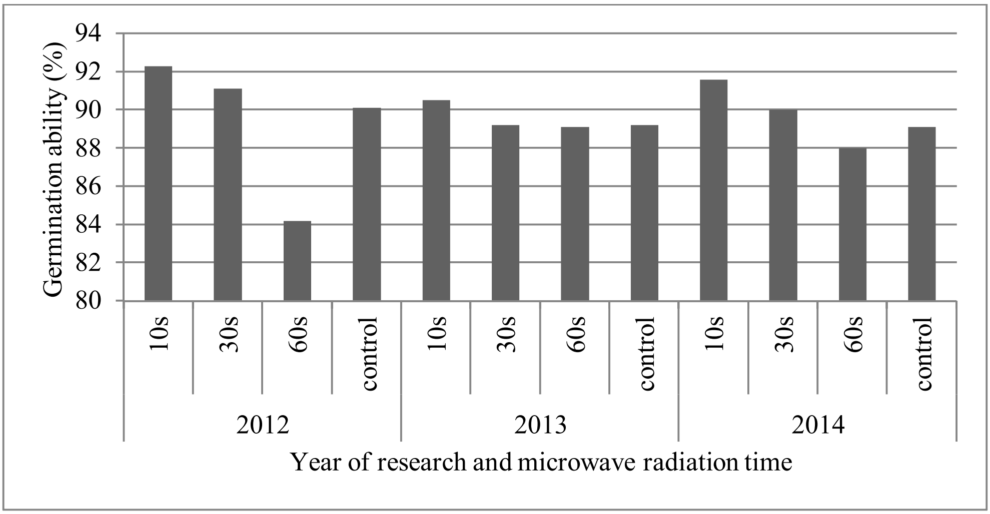

Figure 2. Germination ability of bean seeds in particular combinations of experiment

In each year of realization of the experiment it was found out that samples radiated within 10 and 30 s germinated faster with reference to the sample radiated for 60 s and to the control sample (Fig. 3). In the first case, Maguier's index assumed values within 6.2-6.4 and in the second one 5.9-6.0. In case of the evaluation of the average time of germination of one bean seed, the lowest values of Pieper's index for seeds radiated within 10 s and the highest in the control sample were reported. Interpretation of the value of this index is as follows: the lower the value the higher liveliness of a seed and faster germination, the higher value the longer the germination process. Data presented in Fig. 4 show, with reference to the control (=100%), that 10 s exposition of bean seeds to microwaves caused the increase of the average germination time by 2.9%.

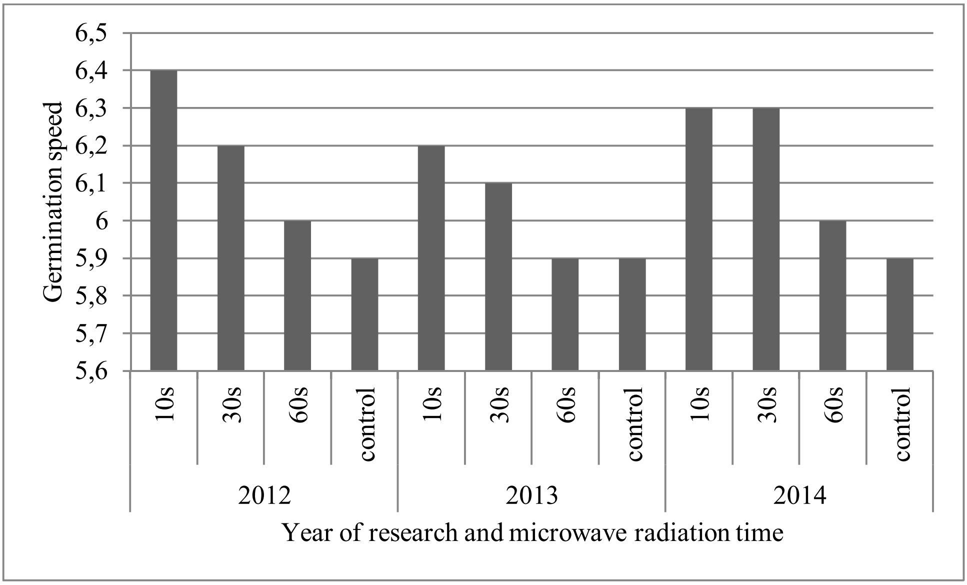

Figure 3. Relative speed of germination of bean seeds in particular combinations of experiment

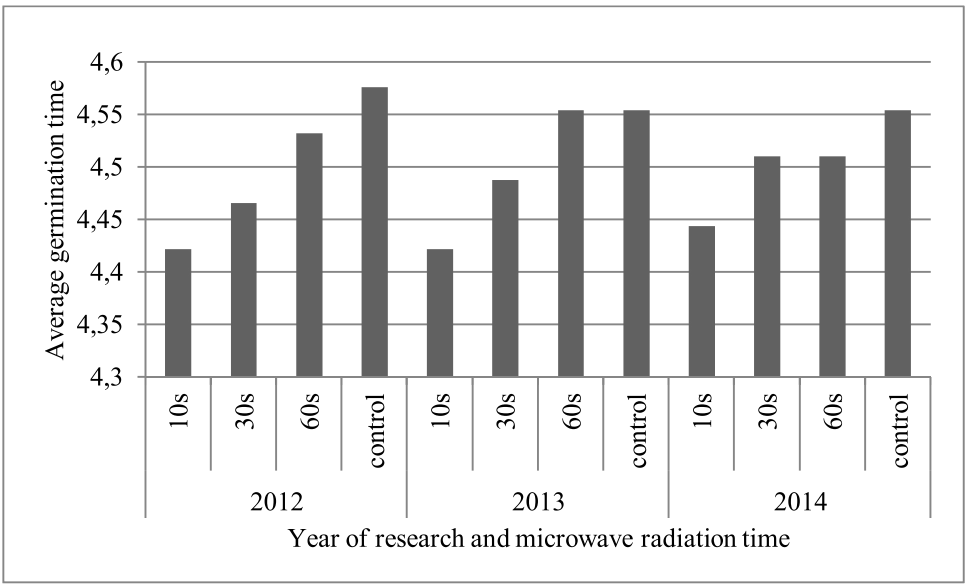

Figure 4. Average time of germination of bean seeds in particular combinations of experiment

Table 2
Result of analysis of variance; impact of research years and radiation of bean seeds with microwaves on the increase of fresh mass of a plant

Quality predictor	Test value of F–Snedecor	Probability test value	Wilks test value	η_p^2
Absolute term	23834.685	0.000	0.007	0.982
Year	13.511	0.000	0.792	0.524
Mf	12.945	0.003	0.812	0.262

Although, the analysis of variance proved significant impact of microwaves on shaping bean plant biomass (significant value $F = 12.9$) the value, calculated for this effect (a quality predictor) η_p^2 was only 0.262 (Table 2). It proves that only approximately 26.2% of the entire variation of the experiment results (biomass increase) may be explained by the impact of microwaves on the bean plant. Despite a low value of the coefficient η_p^2 which describes the size of the microwaves' effect, the quality predictor should be included, since according to the Cohen's scale (Stanisz, 2007) effects below the value of $\eta_p^2 = 0.2$ are insignificant.

Table 3
Groups in uniform average (Spjotvoll-Stoline's test); impact of radiation of bean plants with microwaves on the increase of fresh plant mass (results of research from 2012)

Microwaves radiation time (s)	Fresh mass (g)	Uniform groups 1	Uniform groups 2
60	7.61	****	
30	7.75		****
10	7.81		****
Kontola	7.83		****

Table 4
Groups in uniform average (Spjotvoll-Stoline's test); impact of radiation of bean plants with microwaves on the increase of fresh plant mass (results of research from 2013)

Microwaves radiation time (s)	Fresh mass (g)	Uniform groups 1	Uniform groups 2	Uniform groups 3
60	7.49	****		
30	7.64		****	
(control)	7.71		****	
10	7.86			****

Table 5
Groups in uniform average (Spjotvoll-Stoline's test); impact of radiation of bean plants with microwaves on the increase of fresh plant mass (results of research from 2014)

Microwaves radiation time (s)	Fresh mass (g)	Uniform groups 1	Uniform groups 2
60	7.52	****	
30	7.74		****
(control)	7.78		****
10	7.82		****

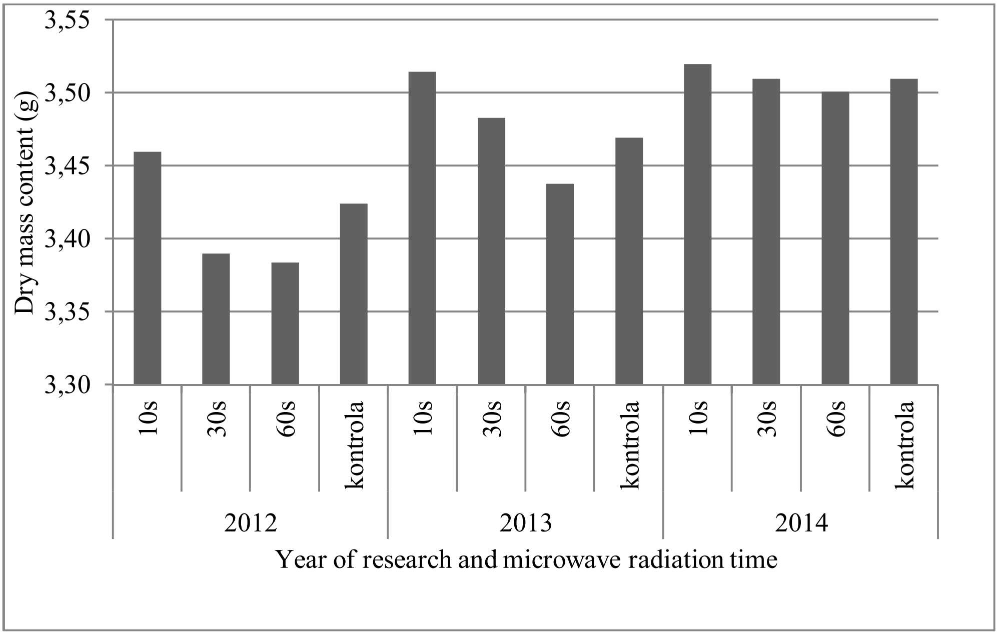

Figure 5. The content of air dry mass in bean plants in particular combinations of the experiment

Visible differences with reference to the control sample in the content of dry mass in bean plants were reported in case of seeds radiated with microwaves within 10 and 60 s. In case 10 s exposition, the content of dry mass was higher at the average by 2.9% and in case of 60 s exposition it was lower by 1.7%. The loss of plant mass as a result of water evaporation (drying) was within 44-46% (Fig. 5). Germination ability at the level of 90-92% obtained after 10 s exposition of bean seeds to microwaves, is higher than the values provided by Szafirowska (2013). This author (Szafirowska, 2013) when comparing a traditional and ecological method of bean cultivation (Aura, Augusta, Igołomska and Wawelska variety) obtained for Igołomska variety the germination ability at the level of 84-85% (germination energy 78-79%, sprouting 74-76%) – these results concern field research thus conditions, when plant is exposed to a more numerous contact with pests in comparison to a laboratory facility. According to Sinh et al., (1999) bean seeds are colonized by a numerous mykoflora (*Fusarium avenaceum*, *Alternaria alternata*, *Cladiosporium cladiosporioides*, *Rhizopus nigricans*, *Fusarium* spp., *Botritis cinerea* or *Fusarium oxysporum*) and saprohytic fungi (*Penicillium* spp., *Mucoraceae*). Wondołowska-Grabowska (2003) claims the same and states at the same time that in case of common bean seeds, this mycoflora is represented the most numerously by *Penicillium notatum*, *Fusarium avenaceum*, *Rhizopus arrhizus* and filamentous colonies. It may be assumed that in case of exposition of bean seeds to microwave radiation (100 W and 2450 MHz) identical reactions appeared as described by Tylkowska et al. (2010) and Friesen et al. (2014) with reference to mycoflora, where in similar experiments radiation with frequency of 2450 MHz was applied and a magnetron operated with the power of 650 W and 1100 W. In the above quoted research, the authors (Tylkowska et al., 2010; Friesen et al., 2014) confirmed the decrease of population of *Penicillium* spp. and *Colletotrichum lindemuthianum* after seeds irradiation. The research carried out by Krupa and Soral-Śmietana (2005), the objective of which was to determine the impact of hydrothermal factors (inter alia microwave heating) on the enzymatic availability of protein selected from bean seeds of Aura (*Phaseolus vulgaris*) and Eureka (*Phaseolus coccineus*) variety proves that microwave radiation causes decrease of the total protein content and decrease of the amount of total mineral compounds (analysed as the ash content). Thus, there is a probability that 60 s radiation time, could cause unfavourable changes in aminoacids structure translating into an initial stage of plant development. The authors quoted above (Krupa and Soral-Śmietana, 2005) do not confirm that microwaves caused significant changes of starch content in bean seeds. According to the author, following experiments concerning the microwaves impact on the bean plants, should include subsequent varieties and the radiation time may be narrowed to 30 s.

Conclusions

1. A positive impact of 10 s radiation of bean seeds on the investigated parameters, which determine the sowing value of bean seeds (germination ability, Maguier's index, Piper's index) were confirmed.
2. Statistically significant differences in the increase of fresh mass between combinations of microwave radiation and the control sample were reported.
3. In all years of research, statistically significant negative impact of 60 s microwave exposition of bean seed on the increase of fresh mass of plants was determined.
4. In 2013, a statistically significant impact of 10 s microwave exposition of bean seeds on the increase of fresh plant mass was reported.

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Rozporządzenie Parlamentu Europejskiego i Rady (WE) nr 1107/2009 z dnia 21 października 2009 r. dotyczące wprowadzania do obrotu środków ochrony roślin i uchylające dyrektywy Rady 79/117/EWG i 91/414/EWG

OCENA WPŁYWU PRZEDSIEWNEJ MIKROFALOWEJ STYMULACJI NASION FASOLI NA PROCES ICH KIEŁKOWANIA

Streszczenie. Celem pracy była ocena wpływu stymulacji mikrofalowej nasion fasoli na proces ich kiełkowania. Badania laboratoryjne prowadzono w latach 2012-2014 z wykorzystaniem kwalifikowanych nasion fasoli (*Phaseolus vulgaris* L.) odmiany Igołomska. Bezpośrednio przed siewem nasiona napromieniowano mikrofalami przez czas 10, 30 i 60 s. Źródłem mikrofal był magnetron działający z mocą 100 W i wytwarzający fale o częstotliwości 2,45 GHz. Zobrazowano przebieg procesu kiełkowania oraz wyznaczono parametry określające wartość siewną nasion fasoli: zdolność kiełkowania, względną szybkość kiełkowania (wskaźnik Maguiera) oraz średni czas kiełkowania (wskaźnik Piepera). Określono świeżą a następnie suchą masę roślin. Uzyskane wyniki pozwalają na stwierdzenie, że mikrofale modyfikują proces kiełkowania nasion fasoli.

Słowa kluczowe: mikrofale, fasola, kiełkowanie

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ANALYSIS OF ELECTRICAL ENERGY CONSUMPTION IN TECHNOLOGICAL LINES IN CIECHANOW DAIRY COOPERATIVE

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ABSTRACT

The paper deals with analysis of electrical energy consumption by technological lines of particular dairy products in Ciechanow Diary Cooperative in 2011. Ciechanow Dairy Cooperative is an average establishment on account of size. The establishment produces milk, sour cream, cheese and curd, butter, homogenised cheese and yoghurt. Based on data provided by the cooperative, actual indexes of electrical energy consumpton were calculated and compared with the values obtained in dairy cooperatives of the selected EU states. In 2011, the average value of the index of electrical energy consumption in Ciechanow Dairy Cooperative was 46.5 kWh·10 hl^{-1} of the processed milk. This value is considerably lower than the average one reported in dairy cooperatives in Poland. The highest amount of electrical energy consumed for milk and milk drinks production is in Sweden, the lowest in Poland and Denmark.

Introduction

Agri-food processing establishments have specific properties which result from the amount and seasonality of processed raw materials, production technology, degree of mechanization of production operations and spatial development (Wojdalski et al., 2006). Consumption of energy carriers in these establishments depends on many factors, among which there are: thermal and physical properties of raw materials, requirements for the product, production technology, size and production structure, technical equipment, degree of production operation mechanization, degree of using the capacity and production organization (Wojdalski et al., 2012). Approximately 80% of the energy consumed by dairy cooperatives is energy which comes from fuel combustion and processing to the form of steam and warm water. The remaining energy consumption is electrical energy necessary to maintain the operation of production lines, cooling systems, ventilation and lighting (Mierzejewska et al., 2011). In the dairy industry, production lines for condensed milk and powdered milk are generally considered to consume the highest amount of heat and energy (BAT, 2005). Based on the research on the technological lines devices on account of electrical energy consumption, spots of big losses of these energy carriers may be easily determined and current indices of unit electrical energy consumption may be improved (Janus, 2005).

The index of unit consumption of electrical energy is used for determination of energy management in processing in the food industry. It is a relation of electrical energy consumed in the processing to the produced amount of products (Domagała, 1986, Wojdalski et al., 1998). Knowledge of indices of energy consumption enables technologists to carry out comparative assessment on account of processing in various industrial establishments (Janus, 2004) and for designers it is indispensable for designing energy of technological lines (Domagała, 1986). According to Wojdalski et al. (2012) the knowledge of the value of indices of energy consumption in particular technological processes is significant on account of rational energy management of an establishment.

Objective, scope and methodology of research

The objective of the research was to analyse electrical energy consumption by production lines of particular dairy products in 2011. The research material comprised data provided by Ciechanow Dairy Cooperative. The dairy cooperative in Ciechanow is equipped with the following technological lines: a milk processing room, continuous method production line for homogenised cheese, curd cheese production room, cheese production room (boiling room, salting room, ripening room) a continuous line for butter production, urban division.

The scope of the research covered:

- determination of electrical energy inputs per unit indices of electrical energy consumption by technological lines in 2011,
- determination of electrical energy consumption ($kWh \cdot 10hl^{-1}$ of processed milk) in particular months of 2011,
- comparison of indices of electrical energy consumption with the values obtained in diary cooperatives in Poland and in the selected EU states.

Results of the research

Based on the results of measurements of electrical energy amounts on technological lines and the mass of the final product indices of unit electrical energy consumption were calculated and presented in table 1.

In 2011 Ciechanow Dairy Cooperative produced 5, 485, 243.6 litres/kilos of products. A considerable amount of 2, 930, 851.25 litres constituted milk (figure 1a and 1b).

From among all analysed production lines, the highest value of unit electrical energy consumption of 40 $kWh \cdot 10hl^{-1}$ was reported on the cheese processing and forming line, and the whey line. A high value of energy inputs per a unit index of energy was reported on the buttering and the yoghurt line and 30% and 36% on the sour cream line, milk reception line, raw milk tanks. The lowest value of the electrical energy consumption index of 2 $kWh \cdot 10hl^{-1}$ was reported on the line for packing in cubes and on the line of fresh cheese, thermized cheese and cream (table 1). According to Marks et al. (2007) differences in the amount of energy inputs result from different capacities, amount and quality of the purchased raw material and the condition of a machinery park in establishments.

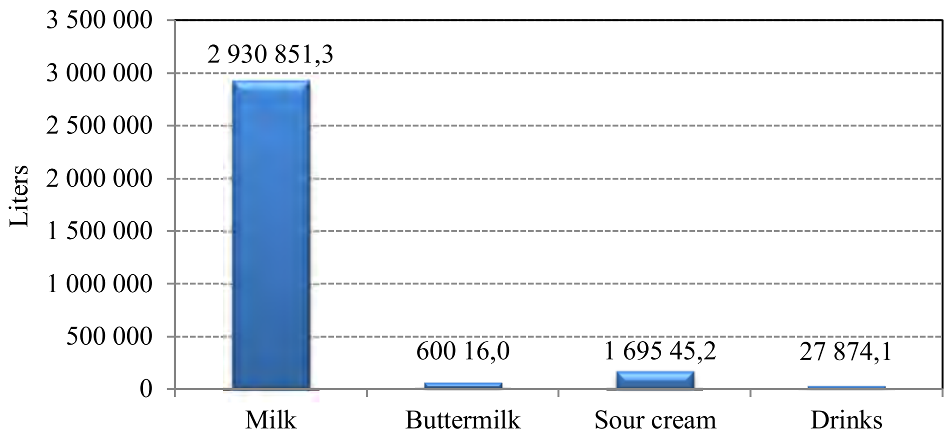

Figure 1a. Type and size of production in Ciechanow Dairy Cooperative in 2011

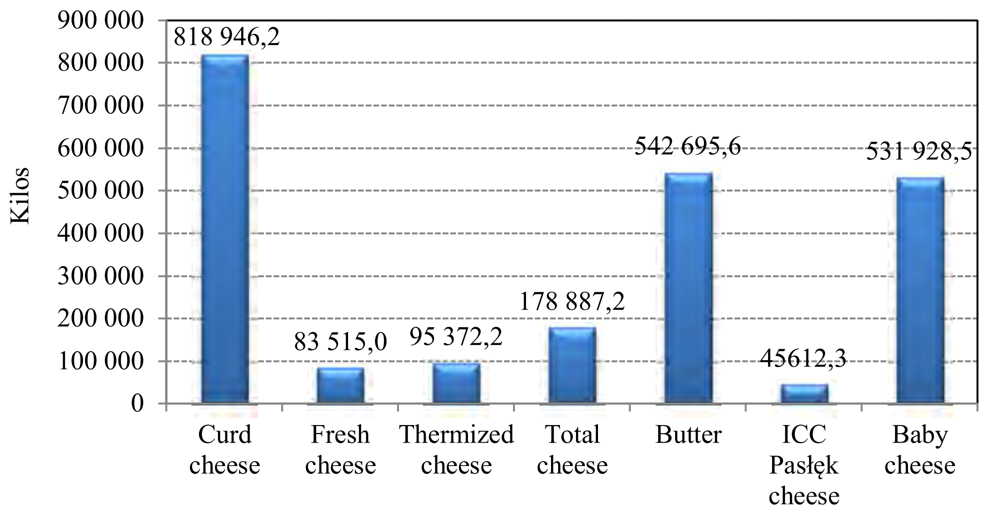

Figure 1b. Type and size of production in Ciechanow Dairy Cooperative in 2011

Table 1
Unit electrical energy consumption (kWh·10 hl^{-1} of the processed milk) by technological lines in Ciechanow Dairy Cooperative in 2011

Technological lines	Unit index of energy consumption (kWh·10 hl^{-1} of the processed milk)
Milk reception line, raw milk tanks	23.3
Line for pouring milk into cartons	11
Line for fresh cheese, thermized cheese and cream	6
Line for fresh cheese, thermized cheese and cream	6
Buttering line	32
Buttermilk line	16
Yoghurt and 30% and 36% sour cream line	30
Processing line for curs and pressing, whey line	10
Line for packing into cubes	2
Line for packing immature cheese and ripening room no. 1	17
Processing and forming line for curd cheese, whey line	40
Confection line for matured cheese and cheese ripening room no. 2	7

According to the analysis of the Polish dairy sector (FAPA, 1998), the unit electrical energy consumption is between 0.6 to 0.8 MWh per 1 tonne of a product. When comparing indices of electrical energy consumption in the selected countries of the European Union and in Ciechanow Dairy Cooperative one may state that the highest amounts of energy for milk and milk drinks production are incurred in Sweden and the lowest in Poland and Denmark. In Ciechanow Dairy Cooperative the index of energy concerning milk and milk drinks producton is within the range stated for Poland. The highest amounts of energy for cheese and whey production are incurred in Finland (Table 2).

Table 2
Consumption of electrical energy (kWh·l^{-1} of processed milk) in the European Union states and in Ciechanow Dairy Cooperative (BAT, 2005)

Products	Sweden	Denmark	Finland	Poland
Milk, milk drinks	0.11-0.34	0.07-0.09	0.16-0.28	0.05-0.06
Cheese, whey	0.15-0.34	0.12-0.18	0.27-0.82	0.06
Powdered milk, cheese or/and milk drinks	0.18-0.65	0.3-0.71	0.28-0.92	0.05-0.09

Source: BAT, 2005

Figure 2 presents average values of the index of electrical energy consumption in Ciechanow Dairy Cooperative in particular months of 2011. Average value of the electrical energy consumption index in the Dairy Cooperative in Ciechanów was 46.5 kWh·10 hl^{-1} of the processed milk. In January and February, the index of electrical energy consumption was at the same level. From March to May the lowest energy consumption was reported. From June to September a gradual increase of energy consumption took place. In November, the value of unit index of energy consumption was the highest.

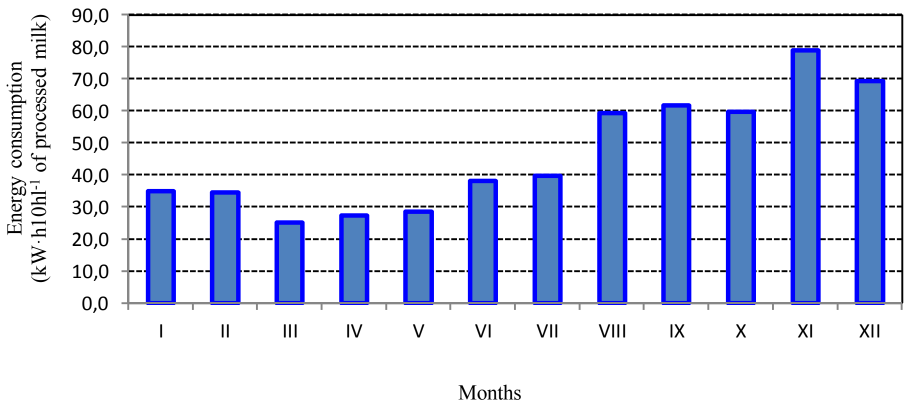

Figure 2. Average electrical energy consumption (kWh·10 hl^{-1} of the processed milk) in Ciechanow Dairy Cooperative in particular months of 2011

Wojtalski (2012) stated that the average value of the energy efficiency index in dairy establishments is 25 kWh·10 hl^{-1} of milk. According to Trojanowska (2010) the index of electrical energy consumption in dairy establishments fluctuates within 55 to 88 kWh·10 hl^{-1} of milk at the average value of 74 kWh·10 hl^{-1} of the processed milk and its value is related to the season of the year.

Participation of electrical energy in the establishment's index of unit energy consumption in the entire dairy industry reaches at the average 15% and is 80 kWh·10hl^{-1} of the processed milk. The increased consumption of electrical energy is characteristic for establishments producing butter and powdered milk as well as ice-creams (BAT, 2005).

Conclusion

1. Based on the research on technological line devices on account of unit indices of electrical energy consumption it was found out that in 2011 the highest amount of energy was consumed on: the cheese processing and forming line, whey line (40 kWh·10 hl^{-1}), buttering line (32 kWh·10 hl^{-1}), yoghurt line and 30% and 36% on the sour cream line (30 kWh·10 hl^{-1}), milk reception line, raw milk tanks (23.3 kWh·10 hl^{-1}). The unit index of electrical energy consumption reached the lowest value on the line for packing in cubes (2 kWh·10 hl^{-1}).

2. In Ciechanow Dairy Cooperative an average unit index of energy consumption is lower than the average reported in Poland. In 2011 average value of index of electrical energy consumption was 46.5 $kWh \cdot 10 \ hl^{-1}$ of the processed milk.
3. Electrical energy consumption, similarly to water consumption depends, inter alia, on the production profile. Dairy Cooperative in Ciechanów does not produce powdered milk, which may result in a considerably lower index of energy consumption in comparison to other national cooperatives.

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ANALIZA ZUŻYCIA ENERGII ELEKTRYCZNEJ NA LINIACH TECHNOLOGICZNYCH W CIECHANOWSKIEJ SPÓŁDZIELNI MLECZARSKIEJ

Streszczenie. W pracy przedstawiono analizę zużycia energii elektrycznej przez linie technologiczne poszczególnych przetworów mlecznych w Ciechanowskiej Spółdzielni Mleczarskiej w 2011 roku. Ciechanowska Spółdzielnia Mleczarska pod względem produkcji jest zakładem średniej wielkości. W zakładzie produkuje się: mleko spożywcze, śmietanę, sery i twarogi, masło, serki homogenizowane oraz jogurty. Na podstawie danych udostępnionych przez zakład obliczono rzeczywiste wskaźniki zużycia energii elektrycznej i porównano z wartościami osiąganymi w zakładach mleczarskich wybranych krajów Unii Europejskiej. W 2011 roku średnia wartość wskaźnika zużycia energii elektrycznej w Ciechanowskiej Spółdzielni Mleczarskiej wyniosła 46,5 $kWh \cdot 10\ hl^{-1}$ przetwarzanego mleka. Wartość ta jest znacznie niższa od przeciętnej notowanej w zakładach mleczarskich w Polsce. Na produkcję mleka i napojów mlecznych największe ilości energii elektrycznej zużywane są w Szwecji, a najmniejsze w Polsce i Danii.

Słowa kluczowe: zużycie energii, linia technologiczna, energia elektryczna, zakład mleczarski

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PURIFICATION AND SORTING OF DRY CORNFLOWER PETALS MIXTURE IN A HORIZONTAL AIR STREAM

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ABSTRACT

The paper aims at determination of parameters, approximate to optimal, of pneumatic separation of the mixture of wild cornflower dried petals obtained by mechanical harvesting. Moreover, the investigated raw material contamination was assessed through comparison and identification of various groups of contaminants and undesired components of the mixture in the basic raw material. Separation was carried out in a horizontal air stream with the use of the designed pneumatic separator. The most efficient and effective was the process of petals separation at the air stream velocity which was 4 $m \cdot s^{-1}$. The amount of the obtained clean petals from the mixture in case of a fraction with bigger dimensions was 48.3%. With the increase of the air stream velocity the coefficient η increases but along with this, the amount of a valuable fraction, which is taken by the stream, grows. At the growth of air stream velocity from V_s=4 $m \cdot s^{-1}$ to V_s=6 $m \cdot s^{-1}$ (within the same size fractions), the highest increase of the coefficient η was in case of the fraction of 400÷500 μm and was 48.3%.

Introduction

Cornflower (*Centaurea cyanus* L.) is a popular weed but at the same time it is herb which grows in grains, on baulks and fallows. It occurs in Europe and Asia as an annual plant or a biennial plant. Its petals are used as a half-product of herbs cultivation and as a medication (Kozłowska, 2002; Kuźnicka and Dziak, 1987; Tomczak, 2007). Herbal raw materials obtained from agricultural farms, herbs plantations or collected ground cover, are, as a rule, highly contaminated with various undesired materials. Dried petals of wild cornflower are in particular difficult for separation and purification, especially when they were previously harvested mechanically (mowing, threshing). Both cornflower petals and other herbs cultivated in the garden as well as wildly growing have various physical properties. Their different parts i.e. flowers, leaves, fruit, seeds, rhizomes and roots are used as a medication or as spices (Kozłowska, 2002; Ożarowska and Jaroniewski, 1989; Panasiewicz et al., 2012; Wierzbicka and Jadwisieńczak, 2003).

Separation of particular components of the mixture in the air stream may take place at any angle of deviation of the stream within 0 to 90° to the level. Thus, at the separation two basic but different processes, namely cleaning in a horizontal and vertical air stream may be applied (Grochowicz, 1994; Tylek, 2003). Furthermore, in each case both suction as well as pumping of air stream are used. Figure 1 presents various structural solutions of cleaning devices, where as a basic separating factor a horizontal air stream was used.

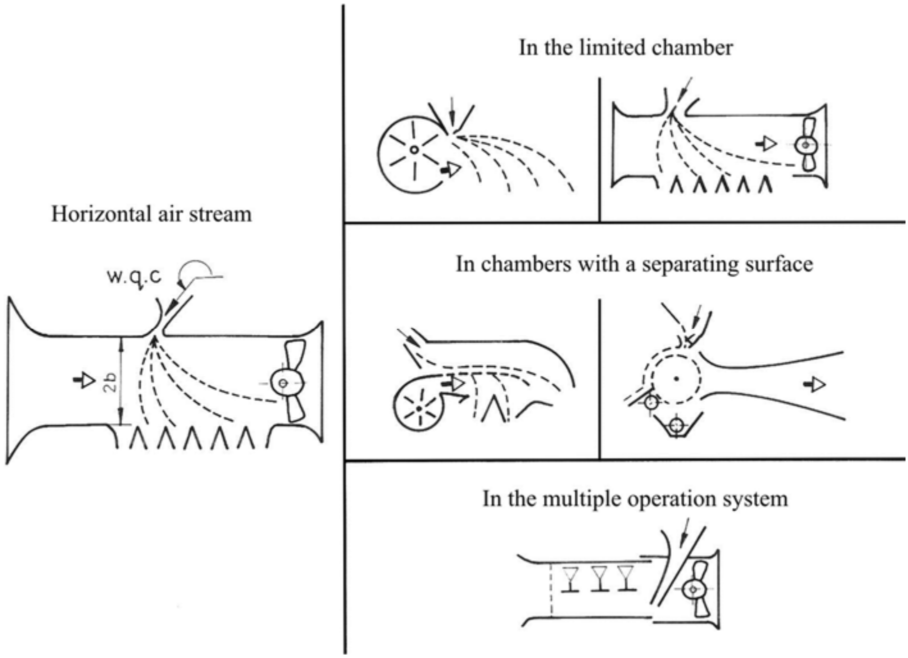

Figure 1. Schemes of pneumatic systems with a horizontal air stream (Grochowicz, 1994): b – width of the pneumatic channel, w – speed of supplying grain mixture, q – amount of the supplied mixture (loading of a channel), c – size which characterizes input contamination of the mixture

The separation process of grain mixtures in this type of systems consists in various vertical tilts of the route of particles which freely fall in the air stream in relation to their aerodynamic properties and the initial speed. Thus, one may state that the separation process is based on the principle of "stretching" the grain mixture in any distance, which enables its precise separation into fractions according to the distance of fall of particles from the place of their inlet to the stream. Both in the horizontal stream as well as in the diagonal one, the separation process takes place at speeds where the vertical component is always lower than the critical speed of seeds (Dmitrewski et al., 1981; Horabik, 2001; Tomczak, 2007).

The principle of separation of grain biological mixtures in the air stream is used both in a special pneumatic separator but also in more or less complex threshing machines and purifying machines (Gierz and Kęska 2011; Grochowicz, 1994; Lorestani et al., 2012; Panasiewicz et al., 2012; Tylek and Walczyk, 2002). Extensive use of this separation method is justified by a simple structure and operation of devices constructed for this purpose.

The objective and the scope of research

The paper aims at determination of approximate to optimal parameters of pneumatic separation of the mixture of dried petals of wild cornflower obtained by mechanical harvesting. The scope of the research covered assessment of the contamination degree of the investigated raw material through comparison and identification of various groups of contaminations and components of undesired mixtures in the basic raw material.

Methods, test stand and test conditions

In order to precisely separate contamination samples, which contain valuable material were tested on the designed pneumatic separator with a horizontal air stream (Fig.2).
The structure of the separator enables multiple iteration of the pneumatic separation process in laboratory conditions. Furthermore, the following were used in the research:

- high scope of variability referred to the direction of air stream flow,
- high scope of variability of air stream intensity (luminar and turbulent flows),
- obtaining great amount of size fractions,
- the use of a precise dispenser for loose materials (a screw type) which ensures regularity of supply of the separated mixture to the working zone.

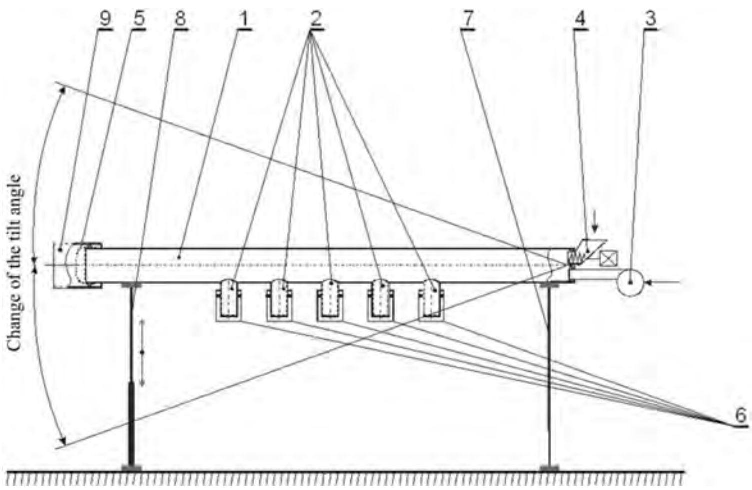

Figure 2. Separator – a stand for measurement of aerodynamic plant materials: pipe channel of pneumatic separator, 2 – outlets of particular fractions, 3 – fan with expenditure regulator, 4 – precise dispenser of raw material for separation, 5 – dust filter (cloth filter), 6 – receiving dispenser of separated fractions, 7 – back base of separation channel, 8 – front base of separation channel (regulated- telescopic), 9 – outlet of purified gas

The structure of device enables precise change of the air stream flow angle from the horizontal to the diagonal one (maximum angle of 30^o). Samples of the mixture of cornflower petals and fractions to be separated of the mass of 40 g each were batched to the container of the dispensing device. Then, a fan which produces air stream with complex velocity within 2÷6.5 $m \cdot s^{-1}$ was activated; next the valve of the container with the mixture was opened. Air stream carried away mixture fractions from the lightest to the highest which caused their dropping to particular containers of a separating pipe. To pneumatic separation samples including the highest amount of valuable fraction (petals) were qualified - dimensions of sieve meshes were from 100 µm to 500 µm and above this dimension. Fraction with dimensions below 100 µm, (mainly contaminations) which does not contain petals was rejected.

Based on the obtained results coefficient of separation effectiveness was computed and it η was:

$$\eta = \frac{b}{b_o} \cdot 100\% \tag{1}$$

where:

b – the amount of contaminations in the separated fraction in the air stream, (kg)

b_o – the amount of contaminations in the batch material, (kg)

Measurement of the air stream speed was carried out with the use of anemometer PROVA AVM-03 (precision of measurement ±0.1 $m \cdot s^{-1}$). Research was carried out in five iterations.

Research results and their analysis

Determination of conditions and parameters of the cleaning and pneumatic sorting process, close to optimal, of dried cornflower petals was preceded by determination of the size distribution of the tested mixture (Table 1). The composition of particular fractions, majority of which contained various contaminations and unuseful waste, basic material was selected, which constituted the most valuable part of the processed material, i.e. petals. Using variability within the scope of dimensions, shape and mass of particles of particular fractions, conditions of the process, which ensured the most efficient and precise effect of separation, were determined. In case of separation and purification of cornflower petals, particles contained in all fractions had similar values of all three aerodynamic parameters, i.e. critical velocity V_k, aerodynamic resistance coefficient k and volatility coefficient k_o (Table 1). Small differences between those parameters practically disable effective separation of the most precious fractions of petals (sort I and II).

Table 1
Aerodynamic characteristics of the selected fractions of cornflower mixtures

Fractions of mixture (dimensions of square meshes of a sieve)	Critical velocity V_k ($m \cdot s^{-1}$)	Coefficient of Aerodynamic resistance k	Coefficient of Volatility k_o
Diameter above φ-500 µm; other contaminations	17.50	0.229	0.0320
Diameter within the scope φ-400÷500 µm; thick contaminations (cornflower seeds)	6.08	0.149	0.2654
Diameter within the scope of φ-315÷400 µm; petals (sort I)	5.32	0.139	0.3466
Diameter within the scope of φ-200÷315 µm; petals (sort II.	4.56	0.124	0.4718
Diameter within the scope φ-100÷200 µm; husks contaminations (cornflower seeds)	4.02	0.116	0.6070
Diameter within the scope φ-50÷100 µm; very light contaminations (cornflower seeds)	3.22	0.099	0.9469
Diameter below 50 µm; dust contaminations	3.16	0.095	0.9801

Except for the aerodynamic characteristics, knowledge of the sort and composition of contamination in the mixture is a significant factor (table 2).

Table 2
Size distribution of the cornflower mixture on Retsch AS 200 sieve shaker

Fractions of mixture (dimensions of square meshes of a sieve)	Sample mass (g)	Participation (%)
Higher than 500	0.72	1.76
400÷500	0.22	0.58
315÷400	1.16	2.90
200÷315	21.44	53.75
100÷200	11.17	28.00
50÷100	3.37	8.45
Lower than 50	1.82	4.56
Total	40	100%

When assessing a percentage participation of particular size fractions it should be stated that the most numerous (53.75%) fraction are particles retained on a sieve with meshes of 200 µm. Less numerous fraction (28.00%) contained particles which remained on a sieve with meshes dimensions which was 100 µm. With reference to the technological value of the investigated mixture, total over 80% participation of those two fractions constitutes a valuable material, consisting of non-crumbled cornflower petals and seeds useful in the processing. In fractions bigger than the mentioned ones, except for small number of petals, also undesired parts of flowers were found, whereas in smaller fractions fine contaminations.

Based on the tests which were carried out, values of the coefficient were computed η, which allowed assessment of the efficiency of the pneumatic separation process of dry cornflower petals in relation to the size distribution and aerodynamic properties and the air stream velocity in the working zone of a separator. Figure 3 presents values of the coefficient η for various fractions of the separated mixture.

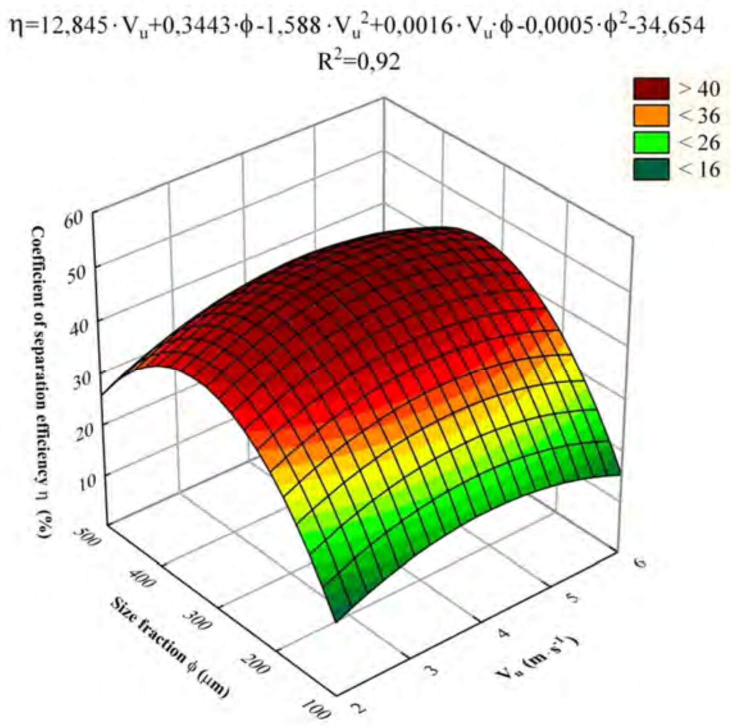

Figure 3. Values of the coefficient of separation efficiency η for particular fractions of the mixture and various speeds of the air stream V_s

The analysis of the obtained values of the coefficient of separation efficiency η indicates relatively varied correlation, which determines relations between the impact of particular parameters on the efficiency of the pneumatic separation process. Change of one of parameters (even to a small extent) leads to a considerable disturbance and deterioration of the separation process of a cover, which impedes determination of optimal conditions for pneumatic separation.

Thus, as a result of pneumatic separation of the cornflower mixture, the highest values of the coefficient η were obtained at the separation of petals in the air stream with the velocity of 4 $m \cdot s^{-1}$. Effectiveness of separation for the fraction of mixture of 400÷500 μm, was the highest and was 48.3%. The lowest values of the coefficient η for all size fractions were reported at the speed of the air stream which was 2 $m \cdot s^{-1}$. At the highest level of air stream velocity (V_s=6 $m \cdot s^{-1}$) efficient separation of petals was obtained (η=42.9) but at the same time more intense air stream carried away also various contaminations and deteriorated thus a general quality of separated petals. Figure 4 presents exemplary fractions of the mixture separated in the horizontal air stream.

Figure 4. Example of selected fractions of the mixture subject to pneumatic separation

According to the analysis of the obtained research results, the undertaken attempt of effective (100%) separation of contaminations from the tested mixture proved to be difficult. A considerable number and amount of particular contaminations was characterized with very approximate (in comparison to features of the basic species) physical properties. It caused that it was hard to remove them in the horizontal air stream. Thus, a conclusion was made that this type of a mixture requires a special technological approach and the use of frequent specific and unconventional set of other cleaning and separating machines. It is also necessary to use multiple iterations of cleaning operations, which elongates the total duration of the process and its energy consumption.

Conclusions

1. Pneumatic separation of the mixture of contaminated cornflower petals in the horizontal air stream on account of the considerable amount of varied and difficult to separate contaminations proved to be low efficient.
2. The most efficient and effective was the process of petals separation at the air stream velocity which was 4 $m \cdot s^{-1}$. The amount of the obtained clean petals from the mixture in case of a fraction with bigger dimensions was 48.3%.
3. With the increase of the air stream velocity the coefficient η increases but along with this, the amount of valuable fraction, which is taken by the stream, grows. At the growth of air stream velocity from V_s=4 $m \cdot s^{-1}$ to V_s=6 $m \cdot s^{-1}$ (within the same size fractions), the highest increase of the coefficient η was in case of the fraction of 400÷500 μm and was 48.3%.
4. Separation in the horizontal air stream may not be one effective method of cornflower petals separation. This method may be related to other manners of cleaning and separation with the use of specialistic cleaning machines e.g. sieving pneumatic and vibrating devices.

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CZYSZCZENIE I SORTOWANIE MIESZANINY SUCHYCH PŁATKÓW CHABRU BŁAWATKA W POZIOMYM STRUMIENIA POWIETRZA

Streszczenie. Praca dotyczy określenia zbliżonych do optymalnych parametrów pneumoseparacji mieszaniny suszonych płatków dzikiego bławatka, pozyskanych poprzez mechaniczny zbiór. Ponadto dokonano oceny stopnia zanieczyszczenia badanego surowca, poprzez zestawienia i identyfikację różnych grup zanieczyszczeń i komponentów mieszaniny niepożądanych w surowcu podstawowym. Separację prowadzono w poziomym strumieniu powietrza z wykorzystaniem zaprojektowanego separatora pneumatycznego. Najbardziej skutecznie i efektywnie proces wydzielania płatków przebiegał przy prędkości strumienia powietrza wynoszącej 4 $m \cdot s^{-1}$. Ilość pozyskanych, czystych płatków z mieszaniny w przypadku frakcji o większych wymiarach sięgała 48,3%. W miarę wzrostu prędkości strumienia powietrza wzrasta współczynnik η, ale wraz z tym powiększa się ilość frakcji wartościowej, którą porywa strumień. Przy wzroście prędkości strumienia powietrza z V_s=4 $m \cdot s^{-1}$ do V_s=6 $m \cdot s^{-1}$ (w obrębie tych samych frakcji wymiarowych), najwyższy przyrost współczynnika η miał miejsce w przypadku frakcji 400÷500 µm i wyniósł 48,3%.

Słowa kluczowe: płatki chabru, pneumoseparacja, zanieczyszczenia

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EVALUATION OF THE SELECTED MICROCLIMATE PARAMETERS IN A FULLY-SLATTED PIGGERY[1]

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ABSTRACT

The microclimate in livestock buildings is very important for health and welfare of farm animals, as well as for the efficiency of livestock production. The aim of the study was to evaluate the microclimate based on measurements of the selected parameters in a two-storey, fully-slatted piggery from July to October 2013. For five selected days, temperature and relative humidity inside the building, the concentration of NH_3, CO_2 and N_2O and air exchange were recorded. The evaluation of temperature and humidity conditions showed that in the monitored piggery, pigs can be exposed to heat stress. The duration of adverse conditions can be as high as 80% of the day in the summer season. Mean daily NH_3 concentrations ranged from 5.92 to 19.51 ppm, and were lower than the limit of 20 ppm. The analysis of the daily distribution of ammonia concentrations showed that in the autumn they were higher than the limit for 40% of the day. Daily average values of CO_2 concentrations ranged from 1092 to 2407 ppm, and were lower than the limit of 3000 ppm. Average daily N_2O concentrations ranged from 0.48 to 0.82 ppm, and did not negatively affect the comfort of the animals.

Introduction

Microclimate in inventory buildings is of particular significance for welfare and health of livestock and influences the efficiency of animal production (daily increase of body mass, milk yield etc.) The existing microclimate conditions in rooms for animals result from a complex influence of many factors, such as: animal species, structure and technical equipment of a building, maintenance system and meteorological conditions (Kołacz and Dobrzański, 2006; Głuski, 2008). Microclimate is a set of climatic factors which directly determine living conditions of an organism or a group of organisms. Its most important parameters include: temperature and relative moisture of air, concentration of harmful gases, air volume stream (exchange of air), lighting and noise (Lewandowski, 1997; Augustyńska-Prejsnar and Ormian, 2012).

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Intensive animal production in changing weather conditions requires stable microclimatic conditions, which are maintained with the use of advanced control systems and techniques of controlling devices (Soldatos et al., 2005). Failure to ensure appropriate microclimate in the building for animals may cause heat stress, which is a body defensive response as a result of unfavourable environmental conditions which disturb the state of homeostasis. For regular course of animals' physiological functions it is necessary to maintain optimal temperature and relative moisture of air, regardless the season of the year (Traczykowski, 2008). These parameters should be considered together since the body reaction on the existing temperature is strictly related to moisture. High humidity and temperature cause lower demand for feed, bigger thirst and difficulties in cooling the body, which reduces daily increases (Witte et al., 2000; Żelazny, 2005; Hoha et al., 2013). On the other hand, low humidity may lead to breathing disorders and may cause the growth of dust concentration. Too low temperature causes an increased demand for feed; however a great part of energy contained therein is used for heating a body and not for the increase of the body mass.

In Europe, the litter systems are thought to better meet the requirements for welfare than non-litter systems (Lyons et al., 1995; Scott et al., 2006). However in the industrial production scale, traditional litter maintenance systems are abandoned. Thus, costs related to ensuring high amounts of straw and work expenditures are reduced. Moreover, by keeping animals in non-litter systems, their hygiene is improved and heat stress is reduced through elimination of manure (litter, which is not only an isolation material, which impedes heat removal by pigs but also is the source of heat (Kołacz and Dobrzański, 2006; Hoha et al., 2013).

The aim of the undertaken research was to asses the selected parameters of microclimate in a piggery with a slatted floor during one production cycle during summer and in the beginning of autumn.

Material and methods

The object of the research was a piggery with a slatted floor, located in Wielkopolskie Voivodeship. It was a modernized two-storey building, where previously fattening was carried on a shallow litter, and the attic served as a feed storage. After it was modernized, pig breeding in a non-litter system was carried out on two storeys (Fig. 1, 2). Comparing it with newly constructed objects, cubic capacity per one pig was considerably lower, which affected the microclimate in a piggery. Manure was stored in containers under the slatted floor. Measurements of microclimatic parameters were carried out on the lower storey of the building, whose technical parameters have been presented in Table 1.

Maintained pigs were fed "wet" and feed was supplied 4 times a day. The building was equipped with a mechanical, temperature controlled, underpressure fan system. There were 3 fans mounted in a piggery with a dimension of 50 cm and a nominal capacity of 7850 $m^3 \cdot h^{-1}$ each.

For five selected days throughout two days from July to October 2013, every 30 minutes the following were registered: temperature and relative moisture of air inside the building (recorder TESTO 175-H2), concentration of ammonia (NH_3), carbon dioxide (CO_2) and nitrous oxide (N_2O) (photo-accoustic spectometer Multi Gas Monitor 1312 by INNOVA). Measurements of temperature and relative humidity took place in four measurement points at the height of 1.5 m, whereas concentration of gases in one point at the same height (Fig.3). Exchange of air was measured constantly and half-hour averages were recorded by the climate controller SK-1D2M (Wesstron, Poland).

Figure 1. View of the piggery

Figure 2. Ground floor of the piggery

Table 1
Selected technical parameters of the investigated ground floor of the piggery

Parameters	Unit	Mean
Dimensions of a storey (length/width/height)	(m)	29.3/9.4/2.3
Cubic capacity	(m^3)	633.5
Number of pigpens	(pcs)	10
Dimensions of a pigpen (length/width)	(m)	8.5/2.7
Pigpen stock	(pcs)	30
Cubic capacity for one piece	($m^3 \cdot pcs.^{-1}$)	2.1
Cubic capacity for one piece	($m^2 \cdot pcs.^{-1}$)	0.77

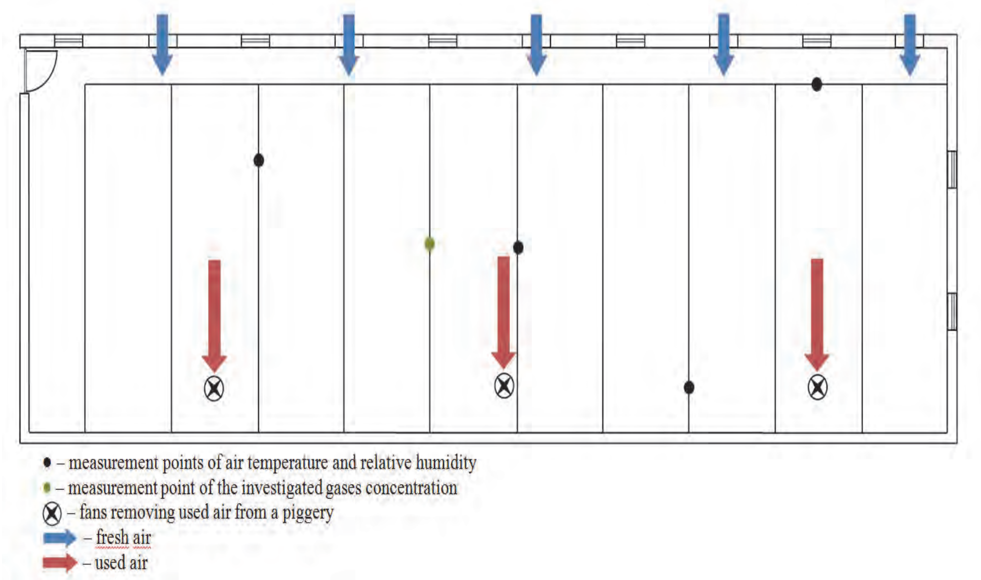

Figure 3. Plan of investigated part of piggery

For assessment of microclimate conditions in the aspect of heat stress, two methodologies were applied. The first one developed by the *National Research Council* in Oklahoma (NRC 1971), based on the temperature and humidity index (THI):

$$.. \quad 1.8 \quad 32 \quad 0.55 \quad 0.0055 \quad 1.8 \quad 26 \qquad (1)$$

where:

T – air temperature in the building, (ºC)
W – relative air humidity, (%)

THI value equals 72 and was assumed as a border of heat comfort for pigs (Chase, 2004). The second one described by Romaniuk and Overby (2005), which assumes that temperature and humidity conditions in the building are optimal, if the sum of temperature value and relative humidity of air is at the level from 85 to 90.

Results and discussion

The period of research covered one production cycle carried out in the summer season and early fall. On each measurement day the number and average mass of animals maintained in a piggery was determined (Table 2).

Table 2
The number and average mass of fattening pigs in the investigated part of piggery

Parameters	Measurement day				
	09/10.07	23/24.07	13/14.08	04/05.09	02/03.10
Number of porkers	291	291	291	291	291
Average mass of a porker	30	45	60	80	105

Results of daily monitoring of temperature and relative humidity of air and exchange of air in the piggery were defined with the use of basic descriptive statistics: arithmetic mean, standard deviation and coefficient of variability (table 3) and daily distribution of recorded values were carried out (fig. 4 and 5).

Table 3
Average daily values of temperature, relative humidity and ventilation rate in the investigated part of piggery

Parameters	Measurement day				
	09/10.07	23/24.07	13/14.08	04/05.09	02/03.10
Air temperature (ºC)	25.5	25.2	23.1	23.9	22.1
Standard deviation (ºC)	1.1	0.9	1.0	0.7	0.6
Coefficient of variation (%)	4.4	3.7	4.0	2.8	2.9
Relative humidity of air (%)	61.6	51.8	62	61.5	58.2
Standard deviation (%)	3.9	7.0	5.4	3.3	4.7
Coefficient of variation (%)	6.3	13.5	8.7	5.4	8.1
Exchange of air ($m^3 \cdot h^{-1} \cdot pcs.^{-1}$)	55.7	53.1	38.9	38.8	20.9
Standard deviation ($m^3 \cdot h^{-1} \cdot szt.^{-1}$)	11.3	9.4	7.0	7.2	6.5
Coefficient of variation (%)	20.3	18.2	18.1	18.6	31.0

Air temperature in the investigated piggery was at the higher level than the recommended optimal values: 18-22ºC at the weight of 30-100 kg (Romaniuk and Overby, 2005). Daily, its fluctuations were very low which is proved by the value of the coefficient of variation which is within 2.8 to 4.4%. Relative humidity of air was more varied (coefficient of variation 5.4-13.5%). Its average values were within 51.8 and 61.6%, which in majority corresponds to optimal values presented in literature (Romaniuk and Overby, 2005; Nawrocki and Klimkiewicz, 2003). In the investigated period daily average exchange of air was within 20.9 and 55.7 $m^3 \cdot h^{-1} \cdot pcs.^{-1}$, which should be considered correct which is proved by the recorded values of carbon dioxide concentration.

Temperature and relative humidity of air inside the inventory building are strictly related and shape the existing microclimate. Thus, these parameters should not be assessed separately. Full assessment of temperature and humidity conditions was carried out based on the value of THI index and according to methodology by Romaniuk and Overby (2005). THI value equal to 72 is considered as a border of heat comfort for porkers (Chase, 2004). Romaniuk and Overby (2005) assume that microclimate in a piggery is optimal, if the sum of temperature and relative humidity value does not exceed 90. Results of assessment were presented in Table 4.

Based on the computed average values of THI index, it was found out that temperature and humidity conditions were maintained at the level insignificantly higher or lower than the thermal comfort limit. Analysis of the diurnal distribution of THI showed that in the summer during hot days, unfavourable conditions may occur for 80% of a day.

Taking into consideration average daily values of T+W, according to the methodology by Romaniuk and Overby (2005), pigs maintained in a piggery within this period were not exposed to heat stress. Analysis of instantenous (half-hour) results of measurements proved that the exceeds of the thermal comfort limit were from 2.1 to 18.8% of a day and they were decisively lower than the computed ones based on the THI index.

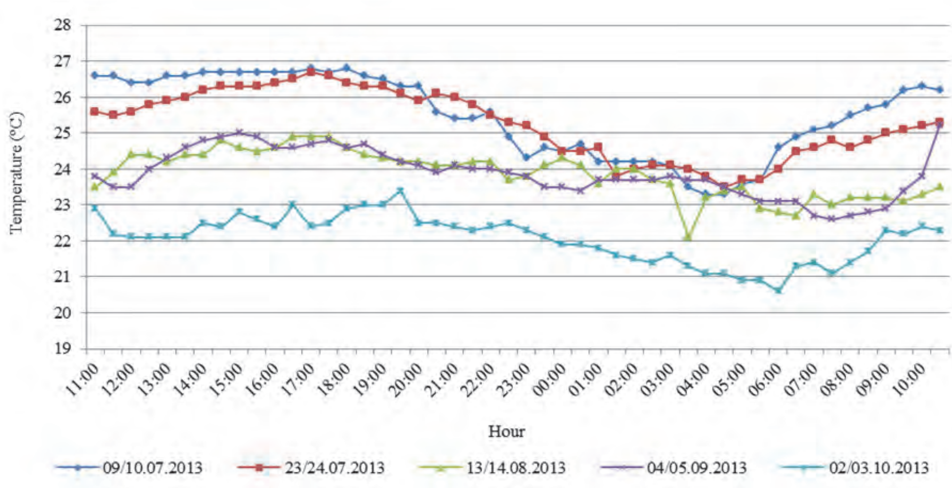

Figure 4. Diurnal variation of air temperature in the investigated part of piggery

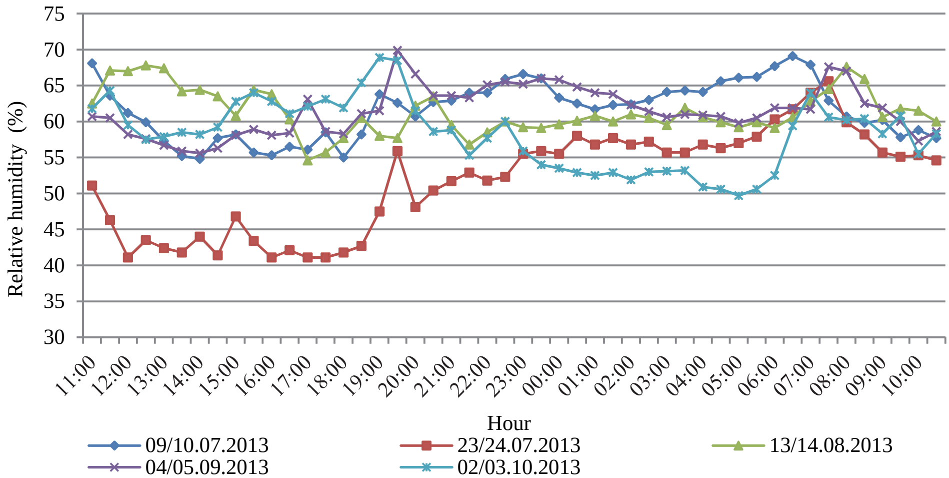

Figure 5. Diurnal variation of air relative humidity in the investigated part of piggery

Table 4
Average daily values of THI and T+H

Parameters	Measurement day				
	09/10.07	23/24.07	13/14.08	04/05.09	02/03.10
THI	73.7	72.2	71.4	71.4	68.6
T+W	87.1	77.0	85.2	85.4	80.3
Exceeding THI (% of a day)	79.2	71.0	29.2	29.2	0.0
Exceeding T+W (% of a day)	18.8	2.1	10.4	6.3	4.2

When comparing results obtained on the basis of two methods one may notice that they differ considerably from each other. It impedes an objective assessment of thermal and humidity conditions in a piggery, thus for a more complete assessment watching animals' behaviour and production results is necessary.

Average values of concentration of the investigated greenhouse gases and ammonia in a piggery were presented in table 5 and their diurnal distribution was presented in figures 6 to 8.

Table 5
Average daily values of greenhouse gases and ammonia concentration in the investigated part of piggery

Parameters	Measurement day				
	09/10.07	23/24.07	13/14.08	04/05.09	02/03.10
Ammonia NH_3 (ppm)	6.13	5.92	8.72	6.62	19.51
Standard deviation (ppm)	1.76	2.01	1.69	1.16	1.56
Coefficient of variation (%)	28.7	34.0	19.4	17.5	8.0
Carbon dioxide CO_2 (ppm)	1092	1222	1471	1113	2407
Standard deviation (ppm)	280	418	229	195	313
Coefficient of variation (%)	25.6	34.2	15.6	17.5	13.0
Nitrous oxide N_2O (ppm)	0.48	0.52	0.53	0.50	0.82
Standard deviation (ppm)	0.07	0.06	0.04	0.04	0.06
Coefficient of variation (%)	14.2	12.1	7.3	7.1	7.9

In the investigated period, average daily concentration of ammonia was from 5.92 to 19.51 ppm and was lower than the admissible value (20 ppm) determined in the Ordinance of the Minister of Agriculture and Rural Development of 2010. Analysis of daily distribution of concentration of this gas was reported only on one day and it was approximately 40% of a day. On this day, average daily air temperature was the lowest which limited air exchange, but porkers' mass was the highest.

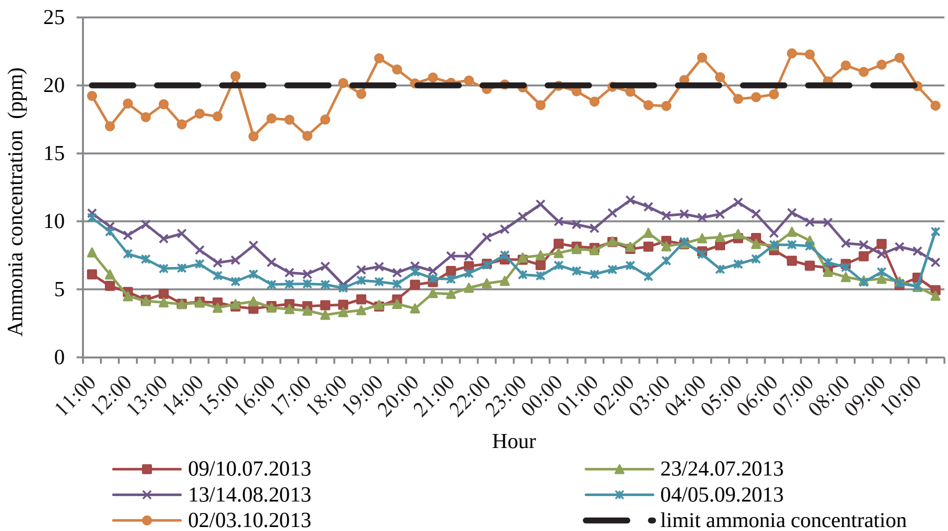

Figure 6. Diurnal variation of ammonia concentration in the invetsigated part of piggery

Instantaneous values of ammonia concentration were within 3.1 and 22.4 ppm. They are identical with majority of results presented in the published papers for pigs maintained on a slatted floor as well as on the deep litter (table 6).

Table 6
The list of ammonia concentration values for fattening pigs in the literature

Source	Maintenance system	Concentration of NH_3 (ppm)
Duchaine et al. (2000)	Slatted floor	1.9-25.9
Louhelainen et al. (2001)		11.7-26.0
Blanes-Vidal et al. (2008)		15.3-28.0
Kimet al. (2008)		7.3-21.4
Sada and Reppo (2008)		4.0-27.0
Ngwabie et al. (2011)		3.9-5.4
Mihina et al. (2012)		9.4-19.9
van Ransbeeck et al. (2013)		8.4-25.0
Sada and Reppo (2008)	Deep litter	6.0-43.0
Staicu et al. (2008)		7.0-25.0
Margeta et al. (2010)		8.0-11.0
Mielcarek and Rzeźnik (2014)		4.9-35.6

Average daily concentrations of carbon dioxide in the investigated piggery were within 1092 and 2407 ppm. They were comparable to results of measurements carried out by Mihina et al. (2012) – 1864-2811 ppm and van Ransbeeck et al. (2013) – 2069-2333 ppm. Insignificant differences may be caused by the stock size and the method of controlling ventilation. In summer the level of daily carbon concentration was decisively lower than the admissible value (3000 ppm) provided in the Ordinance (2010). It proves correctly selected ventilation system performance. Only, at the end of the production cycle, the limit value of CO_2 concentration, which were 4.2 % of a day was exceeded. Maximum concentration of carbon dioxide reported on this day was 3402 ppm and it was by approximately 13% higher than the admissible value.

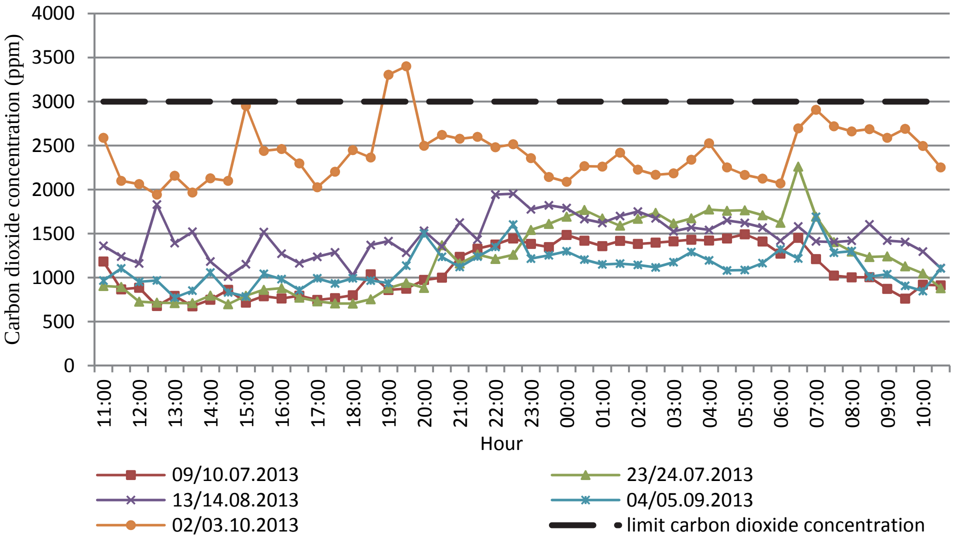

Figure 7. Diurnal variation of carbon dioxide concentration in the investigated part of piggery

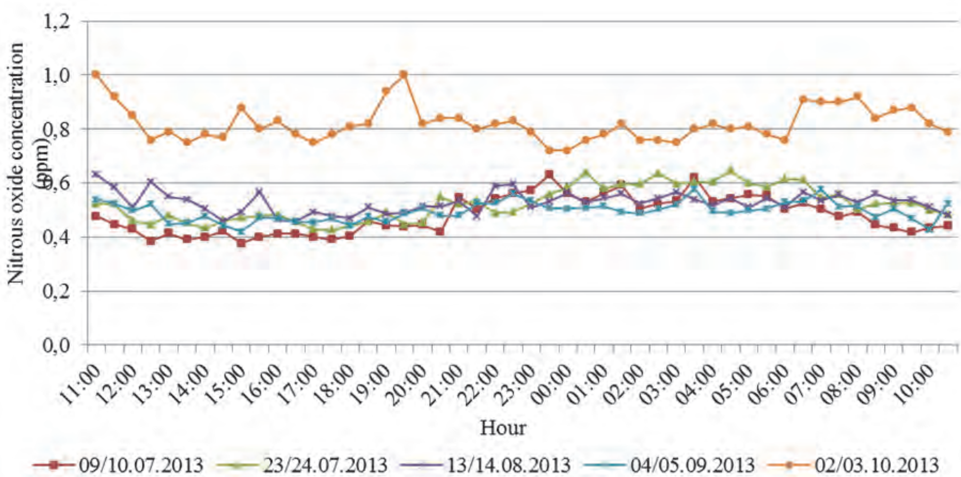

Figure 8. Diurnal variation of nitrous oxide concentration in the ivestigated part of piggery

In the investigated piggery average daily concentration of nitrous oxide was 0.48-0.82 ppm and was decisively lower than the limit value of 35 ppm provided by Nawrocki and Klimkiewicz (2003). Instantaneous values were within 0.38-1.00 ppm. Comparable results were obtained by Blanes-Vidali et al. (2008) – 0.72-0.94 ppm and van Ransbeeck et al.

(2013) – 0.44-1.65 ppm when carrying out measurements in a non-litter piggery. Only Mihina et al. (2012) obtained higher values – 0.81-4.47 ppm.

In summer daily distribution of concentration of the investigated gases have similar courses. At night, concentrations are higher than during the day. It results from the level of air exchange, which depends on the temperature. At night, due to lower temperature, air exchange is lower which causes increase of gas contamination concentration. In autumn, no relation between the concentration of the investigated gases and day were reported. It is caused by lower variability of air exchange during the day, which results from lower daily temperature amplitude.

Conclusion

1. Assessment of temperature and humidity conditions in a piggery showed that in the investigated object, pigs may suffer from heat stress and duration of unfavourable conditions may reach even 80% of a day in summer. Depending on the applied methodology, assessment of conditions in a piggery is varied, which does not allow clear determination of the level of the heat stress of animals. Thus, for more complete assessment, observation of animals' behaviour and production results is necessary.
2. Average daily concentration of NH_3 was within 5.92 and 19.51 ppm and was lower than admissible 20 ppm. Analysis of daily distribution of ammonia concentration proved, that only in autumn, in the final stage of fattening exceeds of approx. 40% of a day took place.
3. In the investigated piggery average daily concentration of CO_2 was within 1092 to 2407 ppm and was lower than admissible 3000 ppm.
4. Values of average daily concentration of N_2O were from 0.48 to 0.82 ppm and did not negatively affect the animal comfort.

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OCENA WYBRANYCH PARAMETRÓW MIKROKLIMATU W TUCZARNI Z PODŁOGĄ SZCZELINOWĄ

Streszczenie. Mikroklimat w budynkach inwentarskich ma szczególne znaczenie dla dobrostanu i zdrowia zwierząt hodowlanych oraz wpływa na wydajność produkcji zwierzęcej. Celem podjętych badań była ocena wybranych parametrów mikroklimatu w dwukondygnacyjnej tuczarni z podłogą szczelinową w okresie od lipca do października 2013 roku. Przez pięć wybranych dni monitorowane były: temperatura i wilgotność względna powietrza wewnątrz budynku, stężenie NH_3, CO_2 i N_2O oraz wymiana powietrza. Ocena warunków temperaturowo-wilgotnościowych w tuczarni wykazała, że w badanym obiekcie, u świń może wystąpić stres cieplny. Czas trwania niekorzystnych warunków może sięgać w sezonie letnim nawet 80% doby. Średnie dobowe stężenia NH_3 wynosiły od 5,92 do 19,51 ppm i były mniejsze niż dopuszczalne 20 ppm. Analiza dobowego rozkładu stężeń amoniaku wykazała, że w okresie jesiennym wystąpiły przekroczenia wynoszące około 40% doby. Wartości średnich dobowych stężeń CO_2 wynosiły od 1092 do 2407 ppm i były mniejsze niż dopuszczalna wartość 3000 ppm. Średnie dobowe wartości stężeń N_2O wynosiły od 0,48 do 0,82 ppm i nie wpływały negatywnie na komfort zwierząt.

Słowa kluczowe: mikroklimat, tuczarnia, stężenie gazów, system bezściółkowy

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ECOLOGICAL PROBLEMS OF POST-HARVEST SEED PROCESSING

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ABSTRACT

Elimination of light additives in the dust form from seed material is a significant problem of post-harvest seed processing since leakage of pneumatic machines systems for cleaning seeds enables dust to get outside which deteriorates the ecological condition of the surroundings. The article presents a developed machine for initial seeds cleaning, which divides air waste into fractions of seed and waste additives and purifies the air which circulates in the closed pneumatic system from silt additives, which deposit in the depositions chamber with difficulties. Models of regression of the functioning process of the developed machine were presented. Rational parameters of the inlet window of a dust collector (Δ = 0.03 m, $\delta_{\dot{z}}$ = 0.012 m, $S_{\dot{z}}$ = 0.16 м, β_P = 155^0) and the edge of the partition wall of compartments of light fractions deposition (x = 0.21...0.23 m and y = 0.160...0.175 m) were determined. The developed machine improves the ecological condition of the environment concerning post-harvest seed processing systems.

Введение

Ворох зерновых культур, поступающий на пункты послеуборочной обработки, из-за упрощения технологии возделывания зерновых культур, недостаточно высокого качества технологического процесса зерноуборочных комбайнов содержит пылевидную, сорную, а также зерновую примеси. Поэтому возникает необходимость уже на стадии предварительной обработки зерна выделения примесей и фракционного разделения их на сорные и зерновые, причем последние представляют ценный кормовой продукт для сельскохозяйственных животных. В результате своевременное и качественное выполнение данной технологической операции будет способствовать повышению семенных и продовольственных качеств зерна, снижению его потерь и увеличению пропускной способности поточных линий (Саитов, 2012, Sysuev и др., 2014, Marczuk и др., 2013).

Второй проблемой при послеуборочной обработке зерна является удаление из зернового материала легких, пылевидных примесей, которые при работе зерно- и семяочистительных машин через неплотности пневмосистем, находящиеся под избыточным атмосферным давлением, поступают наружу. В результате этого повышается запыленность рабочего места обслуживающего персонала и окружающей среды. Одним из решений данной проблемы является применение зерноочистительных машин с замкнутым циклом работы воздушного потока и нагнетание вентилятором в участок воздушного тракта, находящегося под избыточным атмосферным давлением, уже очищенного от пылевидных примесей воздуха (Саитов, 2014).

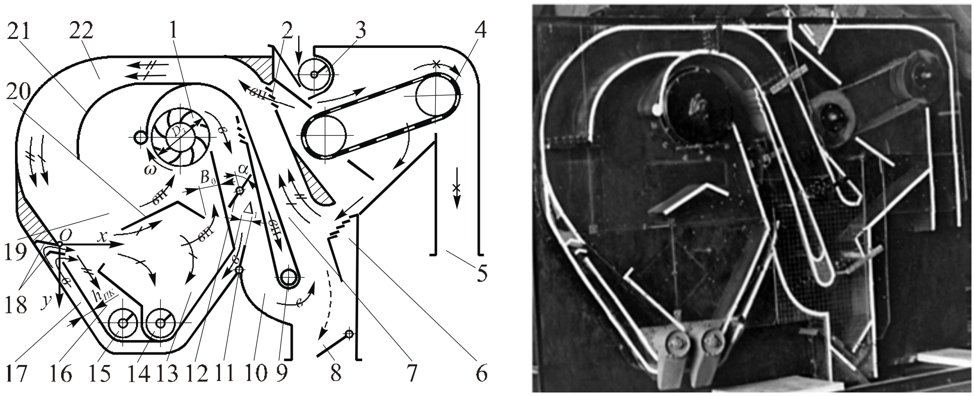
Цель исследований - разработка и исследование машины предварительной очистки зерна с фракционным разделением компонентов зернового вороха и очисткой циркулирующего в замкнутой пневмосистеме воздуха от трудноосаждаемых в осадочной камере пылевидных примесей.

Материал и методы исследований

С учетом вышеотмеченных аспектов на основании анализа исследований рабочего процесса зерноочистительных машин разработана и изготовлена экспериментальная установка для машины предварительной очистки зерна МПО-50Ф (рисунок 1), обусловливающая повышение эффекта очистки зерна за счет интенсификации пневмосепарации зернового вороха и последующего фракционного разделения воздушных отходов на фракции зерновых и сорных примесей (а.с. 1623796 СССР, 1991; пат. 2199402 РФ, 2003), а также очистку циркулирующего в замкнутой пневмосистеме воздуха от трудноосаждаемых в осадочной камере пылевидных примесей (пат. 2266433 РФ, 2005).

Установка изготовлена в продольно-вертикальной плоскости в натуральную величину, а ширина $B_П$ ее проточной части составляла 0,2 м. Рабочее колесо диаметрального вентилятора имеет наружный диаметр D_2 = 0,4 м и частоту вращения n = 690 мин$^{-1}$. Глубина h пневмосепарирующего канала (ПСК) равнялась 0,24 м, величина h_B входного окна пневмокамеры пневмоожижающего устройства (ПОУ) ввода ПСК - 0,04 м, а длина l_B направляющей решетки данного устройства – 0,13 м. Осадочная камера машины оборудована пневмотранспортирующим каналом (ПТК).

При работе установки очищаемый ворох подается через клапан-питатель 3 на сетчатый транспортер 4, с которого сходом идут крупные и соломистые примеси и через патрубок 5 выводятся наружу, а проходовая фракция поступает в пневмосистему. Компоненты зернового вороха, псевдоожижаясь на решетке ПОУ ввода 6, поступают в ПСК 7, где подвергаются воздействию восходящего воздушного потока, создаваемого диаметральным вентилятором 1. Воздушный поток в этом канале выделяет из зерновой смеси легкие сорные и зерновые примеси и выносит их в осадочную камеру 19.



а б

—► - обрабатываемый материал; —/—► - легкие примеси; —×—► - крупные и соломистые примеси; —//—► - фракция фуражного зерна; —в—► - воздушный поток; —вп—► - пылевоздушный поток; - - - - -► - очищенный зерновой материал

Рисунок 1. Технологическая схема (а) и общий вид (б) экспериментальной установки для машины предварительной очистки зерна МПО-50Ф: 1 – диаметральный вентилятор; 2 – жалюзийное окно; 3 – клапан-питатель; 4 – сетчатый транспортер; 5, 8, 14, 15 – устройства вывода фракций; 6 - ПОУ ввода ПСК; 7, 10, 17, 22 – ПСК, воздухоподводящий и перепускной каналы, ПТК; 9 – пылеотделитель; 11, 12 – поворотная и регулировочная заслонки; 13, 16 – отсеки осаждения фракций; 18 – направляющие пластины; 19 – осадочная камера; 20 – осадитель; 21 – криволинейная плоскость

Примеси, вынесенные воздушным потоком из ПСК 7, в осадочной камере 19 под действием силы реакции $\vec{R}$ воздушного потока и силы тяжести $\vec{G}$ движутся возле криволинейной стенки, а в зоне выходного окна ПТК 22 воздушной струей, подведенной через перепускной канал 17 из воздухоподводящего канала 10, подвергаются фракционированию. Легкие сорные примеси выделяются и выносятся из слоя зерновых примесей в отсек осаждения 13. Очищенные зерновые примеси от легких сорных примесей за счет инерционных сил и сил тяжести $\vec{G}$ поступают в отсек осаждения 16. Трудноосаждаемые легкие примеси, выносимые воздушным потоком из осадочной камеры 19 через вентилятор 1, в последующем улавливаются пылеотделителем 9, а затем через его патрубок поступают в циклон, из которого отводятся наружу. Продукты фракционного разделения в осадочной камере 19 из отсеков осаждения 13 и 16 выводятся отводящими устройствами 14 и 15. При закрытии заслонкой 11 перепускного окна в стенке воздухоподводящего канала 10 пневмосистема установки переводится в режим безфракционного сбора и вывода воздушных отходов (Саитов, 2007).

Технологическую эффективность разработанной установки оценивали: производительностью G – количеством обрабатываемого зернового вороха в единицу времени, кг·(м^2·с)$^{-1}$; эффективностью E отделения зерна от примесей, %; эффективностью E осаждения примесей в осадочной камере, %; потерями полноценного $П_З$, мелкого и щуплого $П_{щз}$ зерна в отходы, (%); содержанием a_1 зерновых примесей в фуражной фракции, %; коэффициентом ε улавливания примесей пылеотделителем, %.

Графические зависимости полученных экспериментальных данных аппроксимировали по методу наименьших квадратов (Бронштейн и Семендяев, 1980), при этом статистическая оценка достоверности полученных линейных моделей осуществлялась коэффициентом корреляции r, криволинейных моделей - корреляционным отношени-ем R^2 (Сысуев и др., 1997, Сысуев и др., 2008, Сысуев и др., 2009).

Результаты и их обсуждение

Для проведения экспериментальных исследований использовали искусственно приготовленную зерновую смесь пшеницы сорта Ленинградка влажностью 15%, приближенную по качественному составу к зерну, поступающему от комбайнов на пункты послеуборочной обработки. Полигоны относительных частот компонентов приготовленной зерновой смеси по скорости $\upsilon_{вит.}$ витания представлены на рисунке 2, а их содержание и статистические параметры приведены в таблице 1. Законы распределения полноценных зерен основной культуры и щуплых, битых, дробленых зерен близки к нормальному.

Таблица 1.
Содержание и статистические параметры компонентов в зерновой смеси пшеницы сорта Ленинградка по скорости $\upsilon_{вит.}$ витания

Наименование компонентов зерновой смеси	Содержание компонентов, (%)	Скорость витания	
		$\upsilon_{вит.ср.}$, м/с	σ, м/с
Полноценные зерна основной культуры	85	9,5	0,999
Щуплое, дробленое и битое зерно основной культуры	5	6,2	1,142
Семена сорняков, органические и минеральные примеси	10	3,7	2,32

Проверка гипотезы о нормальном распределении частиц каждой фракции по скоростям $\upsilon_{вит.}$ витания свидетельствует, что наблюдаемые значения критерия Пирсона $\chi^2_{набл.10} = 0{,}64$, $\chi^2_{набл.20} = 0{,}44$, $\chi^2_{набл.30} = 8{,}94$ меньше их табличных критических значений $\chi^2_{крит.10} = 3{,}84$, $\chi^2_{крит.20} = 3{,}84$, $\chi^2_{крит.30} = 11{,}1$ для уровня значимости 0,05 и 1 степени свободы для полноценного и щуплого зерна и 5 степени свободы для сорных примесей. Поэтому гипотеза о нормальном законе распределения полноценных зерен основной культуры, зерновых примесей (щуплых, дробленых и битых зерен основной культуры) и сорных примесей (семян сорняков, минеральных и органических примесей) принимается (Кремер, 2004).

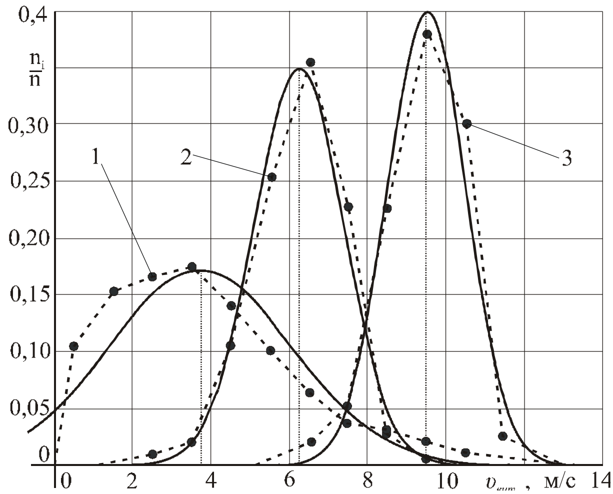


Рисунок 2. Полигоны относительных частот компонентов зерновой смеси пшеницы сорта Ленинградка по скорости $\upsilon_{вит.}$ витания () и соответствующие им нормальные кривые распределения (——): 1 – сорные примеси (семена сорняков, органические и минеральные примеси); 2 – щуплые, дробленые и битые зерна пшеницы; 3 – полноценные зерна пшеницы

Экспериментальные изыскания по определению рациональных параметров входного окна пылеотделителя, расположенного в выходном канале диаметрального вентилятора (Рисунок 1), осуществляли использованием однофакторного эксперимента, применением метода симплексного планирования и реализацией трехфакторного почти ротатабельного плана Бокса-Бенкина второго порядка (Мельников и др., 1980). В результате реализации планов и обработки опытных данных методом регрессионного анализа (Фестер и Ренц, 1983) определены уравнения, связывающие параметры входного окна пылеотделителя (Δ (x_1) – глубина входного окна, $S_{ж}$ (x_3) – длина жалюзийного участка, $\delta_{ж}$ (x_2) – зазор в жалюзи) с коэффициентом ε улавливания им примесей, а также режимов технологического процесса пневмосистемы.

Зафиксировано максимальное значение критерия оптимизации ε=0,98 при Δ=0,03 м и начальном угле установки входного окна пылеотделителя $\varphi_П$=25º в области $\delta_{ж}$=0,012 м и $S_{ж}$=0,16 м в результате применения трехфакторного почти ротатабельного плана Бокса-Бенкина второго порядка (Рисунок 3):

$$Y_{\varepsilon} = 0{,}97 + 0{,}02x_1 + 0{,}035x_2 - 0{,}02x_3 - 0{,}043x_1x_2 - 0{,}023x_1x_3 + \\ + 0{,}023x_2x_3 - 0{,}046x_1^2 - 0{,}026x_2^2 - 0{,}051x_3^2. \quad (1)$$

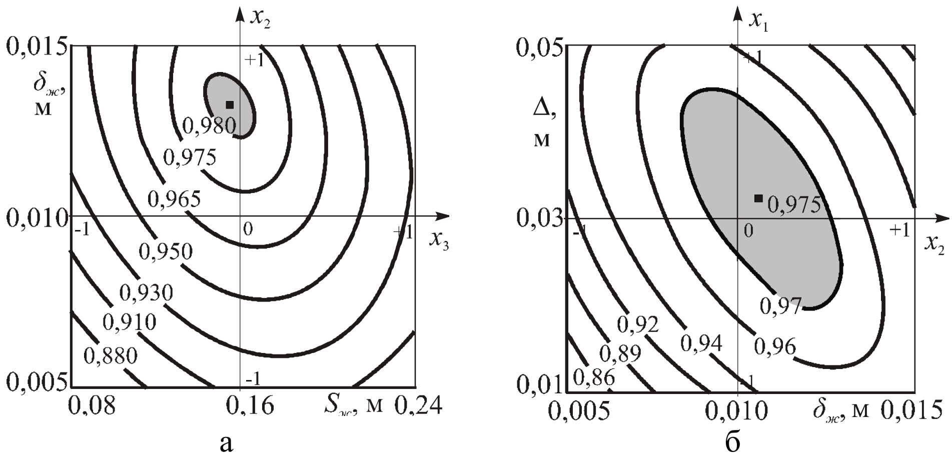


Рисунок 3. Двумерные сечения поверхностей отклика, характеризующие коэффициент ε улавливания примесей пылеотделителем, оснащенным входным окном с жалюзийным участком, при x_1 = 0 (а), и x_3 = 0 (б): [серый прямоугольник] – область максимальных значений ($q_{уд}$=38,07 кг·(с·м^2)$^{-1}$ и Q = 0,48 м^3·с$^{-1}$)

При этом оптимальное отношение расхода воздуха $Q_п$, отводимого через пылеотделитель наружу из пневмосистемы, к расходу воздуха Q, проходящего через диаметральный вентилятор, составляет 0,08…0,10, а зависимость коэффициента ψ полного давления от коэффициента φ' подачи воздуха диаметральным вентилятором имеет нисходящую ветвь, что свидетельствует о стабильной подаче им воздуха в сеть установки.

При выделении зерновых примесей из фракции легких отходов воздушной струей, подведенной в зону выходного окна ПТК, реализован трехфакторный почти ротатабельный план Бокса-Бенкина второго порядка: $x(x_1)$, $y(x_2)$ - координаты кромки разделительной стенки отсеков осаждения сорных примесей и фуражной фракции по оси x и y; $\upsilon'_{ср}(x_3)$ - скорость воздушного потока в зоне фракционного разделения отходов. Полученные адекватные регрессионные модели (F-критерий Фишера, вероятность p =0,95) содержания a_1 зерновых примесей в фуражной фракции, потерь полноценного $П_З$, мелкого и щуплого $П_{щз}$ зерна в отходы (%)

$$Y_{a_1} = 79{,}0 - 3{,}25x_1 + 3{,}125x_2 + 5{,}625x_3 + 3{,}0x_1x_2 - 3{,}5x_1x_3 + 3{,}25x_2x_3 - \\ - 2{,}625x_1^2 - 4{,}375x_2^2 - 2{,}875x_3^2, \quad (2)$$

$$Y_{П_З} = 0{,}019 - 0{,}008x_1 + 0{,}022x_2 + 0{,}032x_3 - 0{,}008x_1x_2 - 0{,}015x_1x_3 + \\ + 0{,}018x_2x_3 + 0{,}007x_2^2 + 0{,}034x_3^2, \quad (3)$$

$$Y_{П_{щз}} = 0{,}294 - 0{,}123x_1 + 0{,}331x_2 + 0{,}481x_3 - 0{,}127x_1x_2 - 0{,}225x_1x_3 + \\ + 0{,}273x_2x_3 + 0{,}112x_2^2 + 0{,}516x_3^2 \quad (4)$$

анализировались методом построения двумерных сечений поверхности отклика. С точки зрения достижения максимального значения a_1=80% и наименьших потерь $П_З$ =0,025…0,042% оптимальные значения координат кромки разделительной стенки отсеков осаждения фракций составили x = 0,21...0,23 м (x_1 = –(0,25…0,75)) и y=0,160...0,175 м (x_2 = 0…0,36) при $\upsilon'_{ср}$ = 8,5 м/с (x_3 = 0). Потери $П_{щз}$ незначительны – 0,35…0,65%. Эффективность осаждения примесей в рассматриваемой камере при работе в режиме фракционного разделения отходов составляет 90%, а при безфракционном их сборе и выводе – 97%, что свидетельствует о вполне удовлетворительной ее работе (Саитов, 1995).

Распределение статических давлений $P_{s\upsilon}$ по длине L_{BT} воздушного тракта экспериментальной установки, снабженной пылеотделителем при Q_n / Q=0,10, удельной зерновой нагрузке $q_{уд}$ = 38,07 кг·(с·м^2)$^{-1}$ и разных расходах воздуха $Q_{пк}$ через ПСК приведены на Рисунке 4.

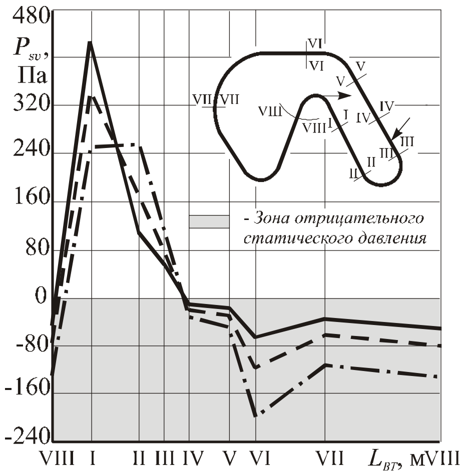


Рисунок 4. Распределение статических давлений $P_{s\upsilon}$ *по длине* L_{BT} *воздушного тракта экспериментальной установки при расходах воздуха* $Q_{пк}$ = 0,24 м^3/с (——), $Q_{пк}$ = 0,34 м^3·с$^{-1}$ (– – –), $Q_{пк}$ = 0,48 м^3·с$^{-1}$ (—— ——)

При этом по оси абсцисс отложены обозначения сечений воздушного тракта, в которых производили замеры, пропорционально длине L_{BT} последнего. Результаты измерений статических давлений $P_{s\upsilon}$, произведенные при расходах воздуха в ПСК $Q_{пк}$=0,24, 0,34 и 0,48 м^3·с$^{-1}$, показывают, что на участке от диаметрального вентилятора до ПОУ ввода давление $P_{s\upsilon}$ избыточное, а по всей остальной длине L_{BT} пневмосистемы - отрицательное. Следует отметить, что нулевое значение давления $P_{s\upsilon}$ находится в зоне ввода зерновой смеси. Это исключает выброс воздуха из пневмосистемы через питающее окно ПСК в приемную часть машины, а затем и наружу. Исходя из изложенного необходимо заметить, что при наличии в верхней части стенки ПСК окна за счет вывода части воздуха из пневмосистемы через пылеотделитель возможен отсос воздуха с пылевидными примесями из приемной части в канал, а далее отвод их в осадочную камеру. При этом уменьшается выброс наружу пылевидных примесей через выводной патрубок крупных и соломистых примесей, что улучшает санитарно-гигиенические условия обслуживающему персоналу. Выполнение окна жалюзийным обусловливает предотвращение срывов и создания вихревого движения воздушного потока на участке сообщения ПСК с приемной частью (а.с. 1794498 СССР, 1993). Наличие вихревого потока значительно будет ухудшать отвод пылевидных примесей вместе с воздухом из приемной части через окно в ПСК. Кроме того, подвод потребного количества воздуха через данное окно в пневмосистему обусловит снижение статического давления $P_{s\upsilon}$ в осадочной камере. Зависимость статического давления $P_{s\upsilon}$ в сечении VШ воздушного тракта установки от коэффициента живого сечения μ_p жалюзийного окна описывается уравнением:

$$P_{s\upsilon} = 129{,}892 - 82{,}680\mu_p + 161{,}473\mu_p^2. \qquad (5)$$

Адекватность уравнения выражается корреляционным отношением R^2, равным 0,93. Из данной зависимости следует, что оптимальное значение μ_p жалюзийного окна должно быть не меньше 0,125, так как при μ_p, больших 0,125, давление $P_{s\upsilon}$ в сечении VШ воздушного тракта установки уже не снижается.

Выводы

Разработана конструкционно-технологическая схема машины предварительной очистки зерна, содержащей приемную часть, снабженную сетчатым транспортером, и пневмосистему, включающую диаметральный вентилятор с расположенным в его выходном канале пылеотделителем с жалюзийным входным окном, воздухоподводящий и пневмосепарирующий с ПОУ ввода каналы, осадочную камеру, оборудованную устройством для выделения зерновых примесей из фракции легких отходов, регулировочную заслонку и устройства вывода фракций.

Получены регрессионные модели процесса функционирования разработанной машины, из которых следует, что оптимальные параметры входного окна пылеотделителя составляют Δ=0,03 м, $\delta_ж$=0,012 м, $S_ж$=0,16 м, $\beta_П$=155º. Максимальное значение a_1=80% ($П_З \leq$0,05%) достигается с параметрами размещения кромки разделительной стенки отсеков осаждения фракций x = 0,21...0,23 м и y = 0,160...0,175 м.

Результаты, полученные при решении поставленной научной задачи, явились основой для выработки рекомендаций при создании машины предварительной очистки зерна МПО-50 с фракционированием легких отходов в осадочной камере и очисткой циркулирующего в замкнутой пневмосистеме воздуха от трудноосаждаемых в осадочной камере пылевидных примесей. Применение разработанной машины в составе зерноочистительно-сушильного комплекса позволяет снизить запыленность рабочего места обслуживающего персонала и окружающей среды на 10…15%.

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PROBLEMY EKOLOGICZNE POZBIOROWEGO PRZETWARZANIA ZIARNA

Streszczenie. Jednym z istotnych problemów pozbiorowego przetwarzania ziarna jest eliminacja z materiału ziarnowego domieszek lekkich w postaci pyłu, ponieważ nieszczelność układów pneumatycznych maszyn do czyszczenia ziarna sprzyja przedostaniu się pyłu na zewnątrz, co pogarsza stan ekologiczny otoczenia. W artykule zaprezentowano opracowaną maszynę wstępnego oczyszczania ziarna, która dzieli odpady powietrzne na frakcje domieszek ziarnowych i śmieciowych oraz oczyszcza powietrze krążące w zamkniętym układzie pneumatycznym od domieszek w postaci pyłu, które są trudne do osadzania w komorze osadowej. Przedstawiono modele regresji procesu funkcjonowania opracowanej maszyny. Ustalono parametry racjonalne okna wlotowego odpylacza (Δ=0,03 m, $\delta_{ż}$=0,012 m, $S_{ż}$=0,16 м, β_P=155º) oraz krawędzi ścianki działowej przedziałów osadzania lekkich frakcji (x=0,21...0,23 m i y=0,160...0,175 m). Opracowana maszyna wpływa na poprawę stanu ekologicznego środowiska w otoczeniu zespołów pozbiorowego przetwarzania ziarna.

Słowa kluczowe: ziarno, pył, czyszczenie ziarna, strumień powietrza

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OPTIMIZATION OF STRUCTURAL AND TECHNOLOGICAL PARAMETERS OF A FERMENTOR FOR FEED HEATING

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ABSTRACT

The basis for obtaining high performance in cattle breeding is correct feeding. Production of a wholesome ration is labour consuming and expensive. Thus, work related to searching for alternative methods of production of wholesome feed is carried out. Synthesis of low value raw material, as a result of which high protein content feed is produced, is one of the methods. A fermentation process takes place in conditions, which cannot be ensured by presently used machines and aggregates. A fermentor, which enables obtaining feed with high content of protein from low value raw material at minimum expenditures, was developed. One of the conditions of correct course of synthesis is ensuring appropriate temperature of feed, where microorganism develop. The objective of the paper is to determine optimal values of factors which affect energy consumption during feed heating. The result was to obtain the regression model which is characteristic for unit changes of energy consumption during feed heating, with the use of which, an optimal angle of embracing the container with a heating belt (159º) and the level of filling the container with feed (100%) were determined. Minimal value of optimization criterion at such values of indexes is 5.14 kJ·(kg·ºC)$^{-1}$.

Введение

Правильное кормление сельскохозяйственных животных является залогом их высокой продуктивности. Поэтому соблюдение баланса кормовых рационов с содержанием необходимого количества в них витаминов, протеина, белка и легкопереваримых углеводов, безусловно, необходимо и важно. Однако выдержать необходимые требования при создании таких рационов довольно сложно. В последнее время во многих странах мира занимаются поиском новых эффективных способов получения легко усваиваемого кормового белка. Одним из наиболее перспективных путей его получения является микробиологический синтез, самым простым видом которого на наш взгляд является применение заквасок (Булатов и Свистунов, 2013).

Процесс получения кормов с высоким содержанием легко перевариваемого белка с помощью заквасок протекает следующим образом. Сначала измельчают исходное сырье (солома, зерно и т.д.) и помещают его в смеситель, туда же добавляют горячую воду и проводят смешивание, получая питательную среду. В полученную смесь закладывают закваску и оставляют на некоторое время, в течение которого протекает процесс ферментации. После окончания ферментации получается насыщенный белками корм. Необходимыми условиями синтеза являются: влажность и температура питательной среды 45…75 % и 48…80 ºC соответственно.

В настоящее время для получения подобного корма используют обычные смесители типа С-12, которые предназначены для смешивания (в некоторых случаях и для запаривания) кормов, но не учитывают процессы, протекающие при синтезе кормов: вид ферментации, влажность и температуру питательной среды. Поэтому совершенствование существующих и создание новых машин для получения кормов с высоким содержанием белка является важной задачей. Для достижения поставленных задач необходимо изучить процессы, протекающие во время синтеза.

Поэтому целью работы определение оптимальных значений факторов, влияющих на энергозатраты при нагреве питательной среды.

Материал и методы исследования

На рисунке 1 представлен разработанный смеситель-ферментер (Оболенский и др., 2014). Он позволяет получать ферментированные корма с минимальными затратами электроэнергии и времени. За счет особенности конструкции повышается интенсификация процесса синтеза, расширяются функциональные возможности агрегата. Смеситель-ферментер состоит из бункера 1, который установлен на раме 2, электродвигателя 8, редуктора 9, пульта управления 10 и системы поддержания постоянной температуры.

Агрегат может работать в комплексе машин, предназначенных для измельчения. Так, например, предварительная подготовка зерна может осуществляться разработанными и оптимизированными дробилками как с принудительной (Савиных и др., 2013в; Сысуев и др., 2008, . Marczuk и др., 2013), так и с пневматической подачей материала (Булатов и др., 2014; Савиных и др., 2012; Савиных и др., 2013а; Савиных и др., 2013б; Сысуев и др., 2008, Sysuev и др., 2014b), в состав которых входит предварительная очистка от сорных примесей (Баранов и др., 2010; Булатов, 2010; Булатов и Нечаев, 2012а, Булатов и Нечаев, 2012б, Sysuev и др., 2014a). Подготовку соломы можно проводить измельчителями (Баранов и Зыкин, 2010; Мохнаткин и др., 2011). Далее измельченное сырье загружается через расположенное в верхней части бункера 1 смесителя загрузочное окно 3.

Исходные компоненты смешиваются рабочим органом 7. Поддержание оптимальной температуры питательной среды обеспечивает соответствующая система, которая включает в себя нагревательный элемент 11 (в нашем случае это тепловая лента ЭНГЛ-1), слой теплоизоляции 12, датчики температуры 13 и реле температуры, регистрирующие элементы которых смонтированы на пульте управления 10.

Выгружают готовый корм выгрузным шнеком 5 через выгрузной патрубок 4, предварительно открыв заслонку 6.

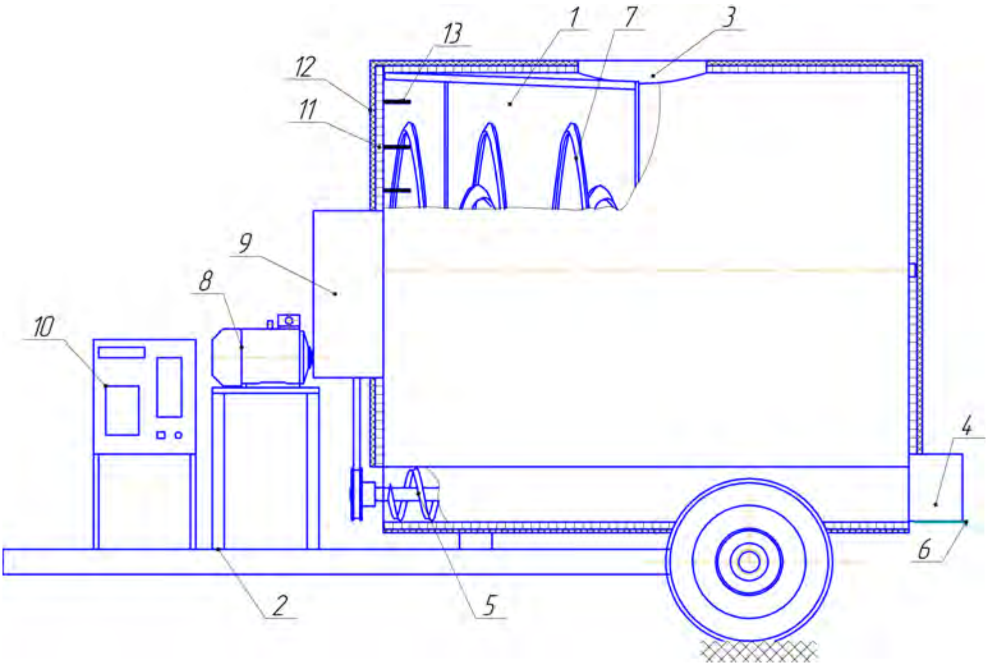

Рисунок 1. Смеситель-ферментер: 1 – бункер, 2 – рама; 3 – загрузочное окно; 4 – выгрузной патрубок; 5 – выгрузной шнек; 6 – заслонка, 7 – рабочий орган; 8 – электродвигатель; 9 – редуктор; 10 – пульт управления; 11 – нагревательный элемент; 12 – слой теплоизоляции; 13 – датчики температуры

Для исследования тепловых процессов изготовлена уменьшенная в 100 раз модель смесителя-ферментера, общий вид и схема которой представлены на рисунках 2 и 3.

Лабораторная установка состоит из бункера 1 цилиндрической формы, наружную поверхность которого охвачена нагревательным элементом 2. Для снижения тепловых потерь в окружающую среду, интенсификации нагрева питательной среды 8, находящейся в емкости 1 поверх нагревательного элемента нанесен слой теплоизоляции 7. Регулирование температуры тепловой ленты и питательной среды осуществляется терморегулятором 5 (модель TL-11-250), данные к которому поступают от датчиков 3 (модель TST84) и 6 (модель TST81) соответственно. Учет потребляемой электроэнергии фиксируется с помощью прибора 4.

Рисунок 2. Общий вид лабораторной установки

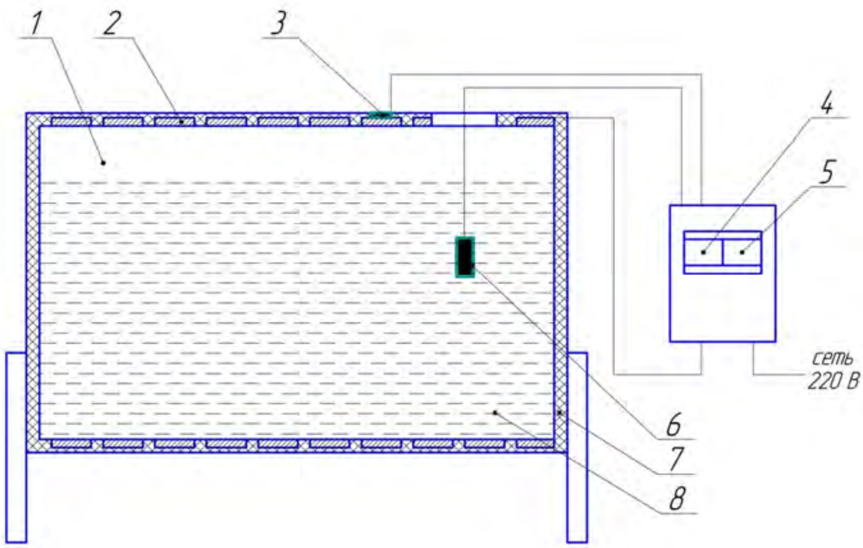

Рисунок 3. Схема лабораторной установки: 1 – бункер; 2 – нагревательная лента ЭНГЛ-1 (180); 3 – датчик температуры ленты TST84; 4 – прибор учета потребляемой электроэнергии; 5 – терморегулятор TL-11-250; 6 – датчик температуры питательной среды TST81; 7 – слой теплоизоляции; 8 – питательная среда

Предварительно были проведены теоретические исследования, по результатам которых определена область исследований (Булатов и Свистунов, 2014).

Чтобы определить оптимальное соотношение исследуемых факторов, обеспечивающее минимальные затраты электроэнергии, реализован полный факторный эксперимент 3^2. Фактор x_1 – угол обхвата бункера тепловой лентой, изменяли от x_{min}=180 до x_{max}=360º с интервалом варьирования Δx_i = 90º (Рисунок 4). Уровень заполнения бункера питательной средой изменяли от 50 до 100%. Интервал варьирования второго фактора составлял Δx_i =25%.

Рисунок 4. Ёмкость с углом обхвата тепловой лентой: а – 360º; б – 90º

Критерием оптимизации y выбрано количество электроэнергии, затраченное на нагрев 1 кг питательной среды на 1 градус, $\frac{кДж}{кг \cdot °C}$.

Матрица плана эксперимента и результаты опытов представлены в таблице 1.

Таблица 1
Матрица плана 3^2 и результаты эксперимента

Последовательность операций	Факторы		Функция отклика y
	x_1	x_2	
Основной уровень, x_{i0}	180º	75%	
Интервал варьирования, Δx_i	90º	25%	
Верхний уровень, x_{max}	360º	100%	
Нижний уровень, x_{min}	90º	50%	
Опыты:			
1	-1,0	-1,0	6,32
2	0	-1,0	6,32
3	1,0	-1,0	9,44
4	-1,0	0,0	5,66
5	0	0	6,07
6	1,0	0,0	7,81
7	-1,0	1,0	5,53
8	0	1	5,53
9	1,0	1,0	6,15

В результате обработки статистических данных получена модель регрессии с доверительной вероятностью 95%:

$$y = 5{,}95 + 0{,}981x_1 - 0{,}811x_2 + 0{,}845x_1^2 - 0{,}625x_1x_2 + 0{,}035x_2^2 \qquad (1)$$

Степень достоверности аппроксимации полученной модели регрессии R^2 составила 95,64%.

Наибольшее влияние на критерий оптимизации оказывает фактор x_1 – уровень заполнения ёмкости.

Минимальное значение функции отклика достигается при следующих значениях исследуемых факторов: x_1 = -0,211 и x_2 = 1 и составляет 5,14 $\frac{кДж}{кг \cdot °C}$.

Для наглядного представления протекающего процесса построена поверхность отклика (рисунки 5).

Увеличение фактора x_1 и уменьшение x_2 приводит к росту удельных энергозатрат. С изменением фактора x_2 в интервале от -1 до 1 наблюдается уменьшение энергозатрат с 6,3 до 5,15 $\frac{кДж}{кг \cdot К}$.

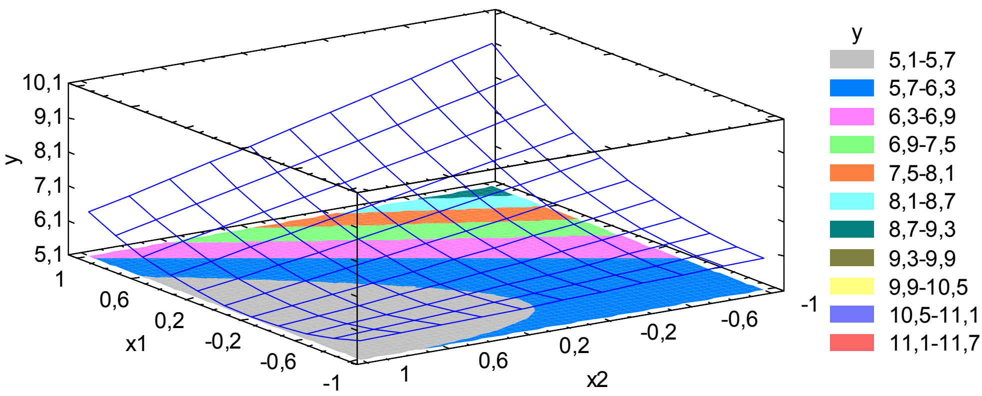

Рисунок 5. Поверхность отклика

Минимальное значение критерия оптимизации наблюдается при x_1=(что соответствует °), $x_2 =$ и составляет $y = \frac{кДж}{кг \cdot °C}$.

Вывод

Получена модель регрессии, описывающая изменение удельных энергозатрат в процессе нагрева питательной среды, с помощью которой определены оптимальные параметры угла обхвата ёмкости нагревательной лентой (159°) и уровня заполнения ёмкости питательной средой (100 %). Минимальное значение критерия оптимизации при данных значения параметров составляют 5,14 kJ·(kg·°C)$^{-1}$.

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OPTYMALIZACJA PARAMETRÓW KONSTRUKCYJNO-TECHNOLOGICZNYCH FERMENTORA DO NAGRZEWANIA POŻYWKI

Streszczenie. Podstawą uzyskania wysokiej wydajności w chowie bydła jest prawidłowe żywienie. Wytworzenie racji pełnowartościowej jest pracochłonne i kosztowne, dlatego prowadzone są prace związane z poszukiwaniem alternatywnych sposobów produkcji wysokowartościowej paszy. Jednym ze sposobów jest synteza surowca małowartościowego, w wyniku której powstaje pasza o wysokiej zawartości białka. Proces fermentacji przebiega w warunkach, których uzyskanie nie są w stanie zapewnić obecnie stosowane maszyny i agregaty. Opracowano fermentator, który pozwala na uzyskanie z surowca małowartościowego paszę o wysokiej zawartości białka przy minimalnych nakładach. Jednym z warunków poprawnego przebiegu syntezy jest zapewnienie odpowiedniej temperatury pożywki, w której rozwijają się drobnoustroje. Celem pracy jest określenie optymalnych wartości czynników wpływających na zużycie energii podczas nagrzewania pożywki. Wynikiem było otrzymanie modelu regresji charakteryzującego zmiany jednostkowego zużycia energii w trakcie nagrzewania pożywki, za pomocą którego wyznaczone zostały optymalny kąt objęcia pojemnika pasem grzewczym (159º) i poziom wypełnienia pojemnika pożywką (100%). Minimalna wartość kryterium optymalizacji przy takich wartościach wskaźników wynosi 5.14 $kJ \cdot (kg \cdot {}^{o}C)^{-1}$.

Słowa kluczowe: model regresji, nagrzewanie, fermentator, czynnik, eksperyment

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THE USE OF MORPHOLOGICAL ANALYSIS IN THE WHEAT QUALITY FEATURE EXTRACTION

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ABSTRACT

In the paper, an attempt towards morphological analysis implementation into grain physical features extraction, with the use of APR software, has been presented. The main objective of the research is to determine the physical characteristics of wheat grains in order to assess the automatic grain quality review. Photographic macro images of wheat grains were taken for the purpose of this study, and then they were processed using the APR application. Properly prepared graphic material has been subjected to segmentation and morphological analysis. Parameters derived from morphological analysis are presented synthetically and form the basis for further research focused on statistical analysis.

Introduction

Grain quality is important for economic reasons and has a direct impact on whether products manufactured from it will have an appropriate quality in terms of both taste and health. From an economic point of view, a reasonable estimate of the grain quality allows correct determination of the price it should be sold for. A grain quality assessment is carried out on the basis of the existing PN-R-74013: 2012 norm in terms of the initial quality control and testing of the organoleptic characteristics of the grain, the PN-R-74015:1994 norm for the determination of contaminants and in accordance with the PN-R-74016:1969 norm for the determination of the content of pests, pollution and grains smut in the sample. Current methods rely on mechanical methods of grains selection. These methods are not only tedious, but in fact they boil down to a series of manual steps and a subjective assessment of the person making the selection. As a result, the process is long, arduous, little repetitive, costly and burdened with the danger of a human error. It is not suitable for mass, continuous verification of grain quality, both during its acquisition from producers and cyclic verification of the quality during storage. Therefore, this is a sufficient evidence to raise the project of automation and objectification of parameters in grain quality evaluation methods. This is an issue of such importance that it has an impact not only on the economic aspect associated with a proper assessment to be adopted for the purchase of grain, but also has a direct link to health security. During the evaluation of the sample it is important to properly diagnose microbial pest infestation of grain, which can in turn have a negative impact on the health benefits of derived products, e.g. too high toxin content in the final product.

One of the grain parameters group which can be automatically and non-invasively determined is the morphology in terms of a seed shape as well as the morphology of anomalies covering the seed, also in terms of a geometric shape. Due to the assumption regarding a low cost of testing the study will be based on:

– visual analysis of the grain,
– surface test in 2D space,
– color images acquisition.

The following section presents the methodological basis in respect of the acquisition and processing of images. The next section focuses on the analysis of samples taken. It is followed by the section presenting the preliminary results of the application of the morphological analysis on the kernel of wheat image. As a conclusion, the authors presented the aspect in which the suggested method can be used in order to study the physical characteristics of the grain, and to find out what impact can the results have on the grain quality testing.

Methodology

The suggested method is based on the automatic images analysis. Therefore, basic issues related to the research involving graphic images as input information should be considered. The first step is referred to the definition of the research objectives and further selection of methods and tools to support their implementation. In this respect, it has been specified that the set parameters describing grains will be assessed just to be used in evaluation of their quality. The paper focuses on parameters of two kinds. The first group comprises the parameters based on the shape of a grain and any anomalies associated with it. The second group consists of the parameters based on the analysis of the distribution of colors on the surface of the object (grain). It should be noted that there are known studies involving the use of color distribution in a sample, which mainly concerned determination of the share of grains of different cereals in heterogeneous mixtures (Tukiendorf et al., 2006). A more detailed description of parameters and their importance in the proposed method will be presented later in this paper. However, the possibility of parameters reading from the image, rely mainly on proper image acquisition.

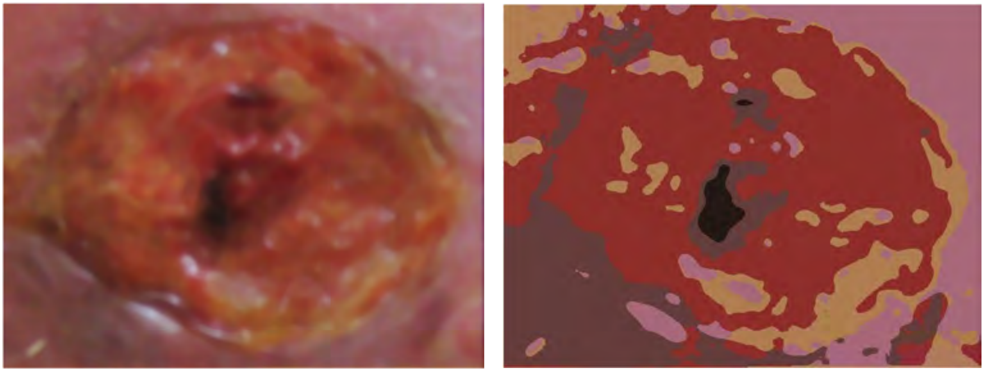
Acquisition is a process that involves loading of a digital representation of the object into the computer application. The most common method is based on the use of visible radiation (light) to illuminate the sample, and detecting reflected light by an appropriate sensor. A physical aspect, including the issue of optics and optoelectronics, due to the nature of this article lies outside the area of the authors' interest. However, what is important and worth emphasizing is the need to respect the principles of correct acquisition of digital images, in particular, the proper illumination of the sample. Appropriate means, in this case, the proper selection of light intensity, the angle of light rays incident on the sample and the temperature of the light spectrum. Any errors made at this stage are fateful in terms of the accuracy and amount of information that can be extracted from the image. Particular attention should be paid to the repeatability of the measurement, which is crucial for the presented method and an absolute condition for metrological validation of measurements. An attention should also be paid to the optimal usage of the light sensor brightness levels characteristics, so that the resulting picture could be characterized by the highest possible rate for all levels of brightness for achromatic images and RGB intensity levels for chromatic images. It is very important for the illuminated sample not to generate additional artifacts in the form of e.g. shadows or areas of high brightness (blinks) so that the analysis could not distort the image and suggest the existence of additional elements or change the shape of the observed object. In the aspect of shadows, multipoint scattered lighting is suggested with possibly homogeneous distribution of light sources throughout the observation area (Szwedziak and Królkiewicz, 2006). Emerging local light flashes result from the optical phenomenon consisting of the light reflection from the relatively smooth surface. However, such a surface has to have a degree of curvature at which clear brightening peaks occur associated with the accumulation of light rays on a relatively small area. The other aspects of the acquisition include:

- frequency of image acquisition,
- resolution, the number of pixels corresponding to their actual body size,
- color depth.

After the acquisition, the image requires processing. Image processing is an operation in which both the input and the output are images. The processing can be performed for a variety of reasons. In the described issue one of the first steps is to prepare the image in the way to eliminate any interference (Tadeusiewicz and Korohoda, 1997).These disturbances can have a very wide variety of sources and may be characterized by different features. A description of all potential distortions resulting from imperfect acquisition methods is beyond the scope of this article.

The main task is to separate the object from the background. This operation is called segmentation. Due to the nature of the proposed method, that assumes the use of morphological analysis (Krótkiewicz and Wojtkiewicz, 2009), the image needs to be binarized, i.e. converted from color to a binary one. In addition to the trivial threshold method the applied APR software offers more sophisticated segmentation algorithms implemented, i.e. one based on selection of any number of areas in the image (Fig. 1).

Each area is represented by the specified rectangle in which pixels are averaged within the range of each of the color components. The result is a single pixel value which then is used as the basis for determination of the distance between the pixel color, and all the pixels of the analyzed area. The APR software allows selection of the metrics which is used to calculate the pixel distance. After making this choice the automatic segmentation of the image occurs producing as many areas as reference areas had been assumed. Following the simple segmentation methods available in the APR it is possible to remove all the pixels except for the pixels having a specific component values. Binarization is the next step. An image processed that way becomes an input to the process of morphological analysis (Krótkiewicz and Wojtkiewicz, 2009).



	X	Y	Red	Green	Blue	Pixels	Share
	410	312	176	124	81	217745	46.353 %
	241	238	37	25	22	27013	5.750 %
	207	140	142	47	43	147608	31.422 %
	465	58	167	105	122	36898	7.855 %
	128	382	100	61	60	40490	8.619 %

Figure. 1. An example of multipoint segmentation by the use of APR software with the output chart

Morphological analysis in the study of kernels characteristics

The image analysis should be understood as a set of operations where input is an image, and the result is a set of values of the studied properties. This is an intermediate step between the processing and classification of images. However, it should be emphasized that the entire examination process may end up on the stage of the analysis, which will provide the necessary information about the object to which it is subject. The selection of the features determines the nature of the analysis (Sonka et al., 2014). One type of analysis is the morphological analysis. It concerns the structure and composition of the objects that are in the area of interest.

In respect to the APR application the morphological analysis is performed only for a binary scene and provides a set of attributes that can be divided into two subsets. In the first there are the features that characterize the scene as a whole (Tab. 1).The second subset contains a description property of individual objects, where the object is understood as a coherent area of white pixels (Tab. 2). If the coherent regions are included in each other, i.e. a coherent area is surrounded entirely by a different consistent area, the internal one is understood as an integral part of the external object (Fig. 2). In other words, the object is the pixel area consistent with all areas of coherent pixels located in its interior.

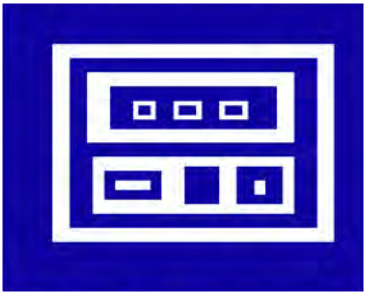


Figure 2. A figure that contains objects within object

Table 1
Features obtained from morphological analysis describing the scene

Number of pixels	The number of pixels on the scene
Width	The width of scene.
Height	The height of scene.
Filled field	Number of pixels that are assigned to objects
Empty field	The sum of pixels building holes in the objects on the scene
Length of external edge	The number of pixels that build external edges of objects
Length of internal edges	The number of pixels that build internal edges of objects
Length of all edges	The sum of two previous attributes
Number of edges	Number of all separable edges
Number of holes	Number of holes that can be designated on the scene
Number of objects	Total number of all objects on the scene

Table 2
Features obtained from morphological analysis describing the object

Object number	The unique number of the object
Filled surface	The number of the pixels filled by the object on the scene.
Empty surface	The number of pixels that describes size of holes in the object
Number of holes	Number of holes (empty spaces) that can be found inside the object
Edge adherent	Number of pixels that are assigned to the edge and at the same time build the frame of the scene
Centre of gravity	Coordinates of the centre of gravity that is computed for the object
Start pixel	Coordinates of the very first pixel found by the function FindNex-tObject
(X1, Y1)	Coordinates of top-left corner of the rectangle circumscribed on the object
(X2, Y2)	Coordinates of down-right corner of the rectangle circumscribed on the object
Length of external edge x	The number of pixels that build external edge of object.
Length of internal edge	The number of pixels that build internal edges of object.
Length of all edges	The sum of two previous attributes.
Number of edges	The number of all edges (external and internal) assigned to the object
Internal edges	The list of internal edges containing length of the edge and coordinates to its start pixel.

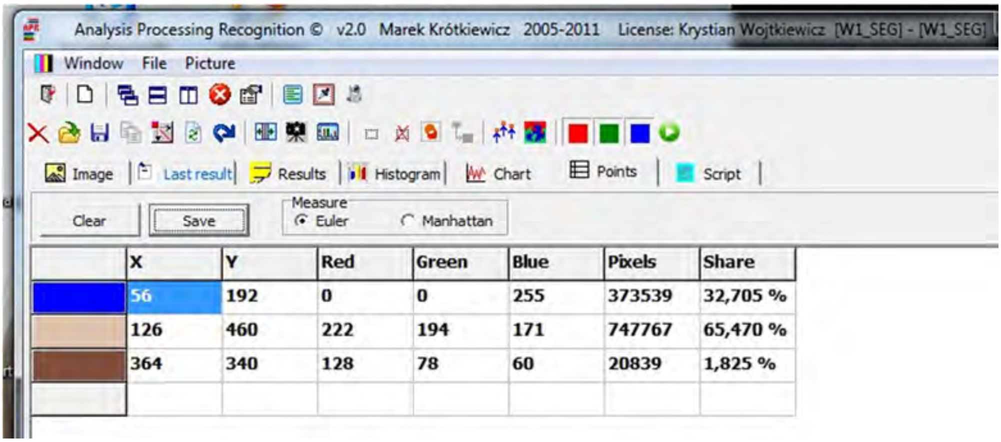
This paper presents an approach to the use of the morphological analysis results performed on the image that has one object, which is the wheat kernel. In order to do that, an image acquisition by means of Nikon D700 camera with Sigma Macro 105mm lens has been performed to give an image of 4288 to 2848 pixels size and 8-bit color depth for each of the three RGB components. The output image has been shown in Figure 3.

Figure 3. Macro image of wheat caryopsis

The obtained image has been subjected to processing by the use of average filter mask of 9x9 pixels size. Then, a median filter was used with the mask equal to the square on the side of 9 pixels. It reduced image noise without introducing significant blurring (Russ and Woods 1995).The next step was to use a multi-level segmentation based on an algorithm which consists in determination of reference pixel blocks, and then calculation of the distance in color space between them and all the pixels in the image. Each of the pixels in the image is assigned to one of the categories (represented by the reference pixel) according to the minimum distance algorithm. The study was performed for both the Euclidean and Manhattan metric. However, the difference in the results obtained from those two metrics is not essential for the analyzed images. The steps of actions are illustrated in fig. 4.

Figure 4. Effects of consequent steps of wheat caryopsis image processing.

Pixels in the scene have been segmented into three classes (Fig. 5). First class represents the background image, the second surface of the grain, and the third the groove. After segmentation, the APR application allows image to be binarized selectively choosing the class of pixels on the basis of their RGB values. As a result of binarization, i.e. transformation of the achromatic image to the binary one, pixels of the selected class are represented by white pixels. At the same time, all the pixels that do not belong to this class, thus are assigned to the other one, take the value of black color.



	X	Y	Red	Green	Blue	Pixels	Share
	56	192	0	0	255	373539	32,705 %
	126	460	222	194	171	747767	65,470 %
	364	340	128	78	60	20839	1,825 %

Figure 5. The table from APR with the statistics of chosen pixel classes.

In the binarized image minor artifacts have been removed successively by the erosion and closing operations. The operation of the so-called erosion is a minimum filter and operates on the basis of the algorithm consisting in replacing all the white pixels to black when they are adjacent to at least one black pixel. This operation is opposite to the dilation operation, which is known as the maximum filter and involves the replacement of all the black pixels to white, as long as they are adjacent to at least one white pixel. The closing operation is based on the sequence of the two operations in a specific order, namely the first dilation operation and then erosion (Tadeusiewicz and Korohoda 1997). As a result of the operations performed relatively, smooth areas, that are the right material for morphological analysis, were obtained (Fig. 6).

Figure 6. Binarized wheat caryopsis image.

The use of binary analysis

The proposed method of analysis assumes the possibility of the grain quality analysis based on the analysis of each grain in the sample independently. Assuming that in the first stage, image processing will be carried out in accordance with the procedure allowing obtaining the optimal input image, the morphological analysis can be carried out in order to determine the parameters of a grain and furrows independently. The following is a sample script that carries out binary analysis procedure in the APR:

```
apr.pathpictures()
apr.imload("ziarno_binar.jpg")
apr.imclearmorfologyinfo()
apr.immorfology()
t = apr.imgetmorfologyinfo(0)
n = t[11]
apr.print("Number of objects: "..t[11])
for i,v in ipairs(t) do
 apr.print("["..i.."] = "..v)
end
for i=1, n do
 t = apr.imgetmorfologyinfo(i)
 apr.print("--- Object number: "..i.." ---")
 for i,v in ipairs(t) do
  apr.print("["..i.."] = "..v)
 end
end
apr.immorfologyinfo()
apr.message("OK")
```

The analysis outputs a set of features describing the scene as well as sets of features describing all detected objects in the scene. The analysis led to the identification of five independent objects, 4 of which were rejected as artifacts due to the very small size (less than 100 pixels). The remaining object has been identified as a kernel whose value characteristics are shown in Table 3.

Table 3
Features obtained from morphological analysis for the object identified as caryopsis

Object number	2
Filled surface	740837
Empty surface	23059
Number of holes	7
Edge adherent	0
Centre of gravity	383.4258, 760.3822
Start pixel	377, 66
(X1, Y1)	29, 66
(X2, Y2)	748, 1463
Length of external edge x	3223
Length of internal edge	2322
Length of all edges	5545
Number of edges	8
Internal edges	90, 1027, 433, 246, 54, 391, 81

The values should be scaled (normalized) to obtain the values in SI units. Standardization issues are extremely interesting as such, but it goes far beyond the scope of this paper and will not be presented in it. This task, however, is only relevant for the calculation of the size and parameters that must be given in real units, i.e. for example the length and width of the kernel. But there are many indicators that are dimensionless, and at the same time allow the assessment of the object. Factors that can be identified in this group are among others: coefficient contour of the object, circuit coefficients, Malinowska factor, Haralicka factor or Danielsson factor.

Conclusion

This paper presents an application of the binary image analysis method to determine the characteristics of the grain. In the study, the wheat caryopsis image has been acquired, which was transformed, and then underwent the morphological analysis. The results obtained allowed stating clearly that this method enables precise determination of the basic parameters of kernels, which can then be used as an input element for the multi-criteria analysis based on the aspect ratio. The authors also pointed out that by the use of the APR software, information on the distribution of colors on the surface of the grain through the use of multi-point segmentation can be easily obtained.

In the future, the authors will focus on conducting a series of experiments in order to obtain statistical material to allow it to draw a hypothesis on the parameters characterizing the grain quality. This applies to both the parameters and the coefficients obtained based on the morphological analysis of the object, as well as the data on color characteristics of the surface of the kernel.

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ZASTOSOWANIE ANALIZY MORFOLOGICZNEJ W BADANIU CECH JAKOŚCIOWYCH ZIARNA

Streszczenie. W artykule opisano próbę zastosowania metody analizy morfologicznej do określenia cech fizycznych ziarniaka pszenicy przy wykorzystaniu aplikacji komputerowej APR. Głównym celem badań jest określenie cech fizycznych ziarniaków pszenicy pozwalających na ocenę jakościową ziarna w procedurze automatycznej. W ramach badań wykonano zdjęcia fotograficzne makro ziarniaków pszenicy, które następnie poddano przetwarzaniu przy użyciu aplikacji APR. Odpowiednio przygotowany materiał graficzny poddany został segmentacji i analizie morfologicznej. Parametry uzyskane z analizy morfologicznej zostały przedstawione w ujęciu syntetycznym i stanowią podstawę dalszych badań na gruncie analizy statystycznej.

Słowa kluczowe: komputerowa analiza obrazu, aplikacja komputerowa APR, analiza morfologiczna ziarno konsumpcyjne, cechy fizyczne ziarna

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EFFECT OF SPRAY APPLICATION PARAMETERS ON THE AIRBORNE DRIFT[1]

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ABSTRACT

The objective of the study was to determine the effect of the spray boom height and liquid pressure on airborne drift during spray application. A lift mounted sprayer with a 12 m spray boom and standard flat fan nozzles LU 120-03 (Lechler) was used in the field trials. The treatments were made for all combinations of the boom heights 0.35, 0.5 and 0.75 m, and liquid pressures 0.15, 0.3 and 0.5 MPa. For each treatment the sprayer was driven at the velocity of 6.0 km·h^{-1}, five times over the distance 60 m. The fluorescent dye BSF was sprayed and collected on the samples attached on 4 m masts. The analysis of BSF deposition on the samplers proved the significant effect of both the boom height and the liquid pressure on the airborne drift. The lowest drift was observed for the pressure of 0.15 MPa regardless the boom height. For these parameters the drift was reduced by 50% compared to the standard situation with the boom height of 0.5 m and the pressure of 0.3 MPa. Raising the boom up to 0.75 m and the pressure to 0.5 MPa resulted in 270% increase of the drift.

Introduction

The quality of the crop protection treatment, namely the uniform distribution of the crop protection products applied on the pests or pathogens infected vegetative organs of plants, which ensured high biological effectiveness, has been the basic objective of the protection technique until recently. However, numerous cases of environmental pollution by crop protection products in regions, where intensive plant production was carried out forced out care for natural environment. Also in Poland for the last dozen or so years, provisions concerning the use of crop protection chemicals, which impose on the operator of sprayers the obligation to obey numerous limitations e.g. the use of buffer zones, have changed. Also,

[1] The research was carried out within measure no. 1.20 "Development of crop protection chemicals precise application method in order to limit pollution of water, soil and other elements of environment" of the Multiannual Programme *"Development of sustainable methods of horticultural production in order to ensure high biological and nutritive quality of horticultural products and to maintain biodiversity and protection of their resource" financed by the Ministry of Agriculture and Rural Development.*

the EU directive on sustainable use of pesticides obliges the Member States to limit threats related to their use with regard to people and natural environment (Directive of the European Parliament and the Council 2009/128/EC of 21st October 2009). One of the biggest threats for water and aquatic organisms is an unavoidable side phenomenon of the spraying process, which is spray drift (Doruchowski and Hołownicki, 2003).

The quality of the treatment and spray drift are two important issues of the crop protection technique. The quality of the treatment is significant in the aspect of spray coverage which to a great extent depends on the type of nozzles, their dimensions and working pressure, and hence droplet size. On the other hand the size of droplets as well as speed and direction of the spray jet affect sedimentation and airborne drift (Van de Zande et al., 2008; Zhu et al., 1994; Knewitz et al., 2002; Castell, 1993; Ganzelmeier, 2000). Measurement of sedimentation drift distribution is significant for assessment of the risk of surface water contamination, while measurements of the airborne drift profile are used to assess the risk with reference to inhalation effects and contamination of plants with an extended spatial form within the field borders (Miller et al., 1989; Taylor and Anderson, 1991). Atmospheric conditions i.e. wind velocity, air temperature and humidity are significant factors which influence both sedimentation and airborne drift (Nuyttens et al., 2006). According to literature the airborne drift decreases along with the increase of the height on which samples are placed, whereas it increases along with the increase of the wind velocity (Guler et al., 2007). While the sedimentation drift was the object of numerous works, few results of research concerning airborne drift are available. Thus, in the Agro-Engineering Dept of the Research Institute of Horticulture in Skierniewice such investigations for various spraying techniques were undertaken.

The objective of the research

The objective of the research was to determine the impact of spray boom operation height and spray pressure on airborne drift.

Methodology of research

Measurements of airborne drift were carried out with the lift-mounted sprayer, equipped with a 12 m spray boom and a 400 l tank. Lechler LU 120-03 nozzles were mounted on the spray boom. The sprayer was driven at travel velocity 6.0 $km \cdot h^{-1}$ on 60 m long test plot. For each combination of the spray boom height (0.35; 0.5; 0.75 m) and working pressure (0.15; 0.3; 0.5 MPa) the sprayer was passing five times over the plot while spraying a water soluble fluorescent dye (BSF) at the concentration 0.3%, according to methods used in drift tests (Bode et al., 1976; Van De Zande et al., 2000; Heijne et al., 2002). Sensitive fluorometric techniques ensure detecting vary small amounts of BSF collected on samplers in form of droplets smaller than 100 µm, or dry particles remaining after evaporation of water from the droplets (Arvidsson et al., 2011). During the field trials, wind velocity with a perpendicular direction to the sprayer driving direction, temperature and air humidity were recorded. Airborne drift was collected on four samplers in form of porous balls (plastic dish washers, 70 mm in diameter) attached on the masts located 5 m from the border of the treated plot, i.e. from the last nozzle on the spray boom. The lowest sampler was 1 m above the ground and the top one at 4 m height (Fig. 1). Two masts with two vertical lines of samplers (Fig. 2) were used to make for four replications of spray collectors at each height.

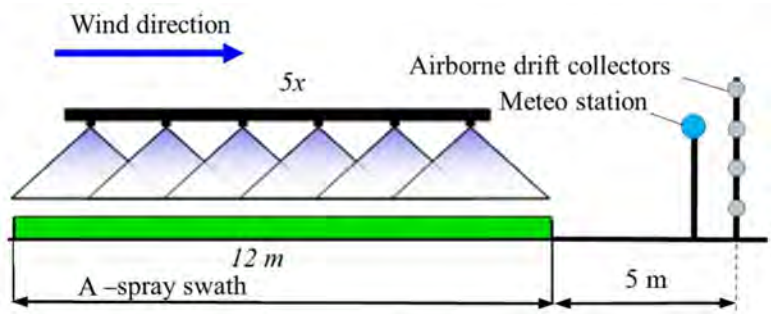

Figure 1. Layout of experiment

Fluoroscent dye was extracted from each sampler separately in tight plastic couvettes in the volume of 400 ml of deionaised water. After the 15 minute shaking a uniform solution of a fluorescent dye was subjected to the measurement of BSF concentration with the use of spectrofluorometer PerkinElmer LS 55. The obtained results were expressed in percentage of the applied dose of a fluoroscent dye. A two-factor analysis of variance and Duncan's range test at the level of significance of P = 0.05 was carried out on data transformed according to Box-Cox with parameter λ = - 0.211098:

$$X'_{\lambda} = (x^{\lambda} - 1) \cdot \lambda^{-1}$$

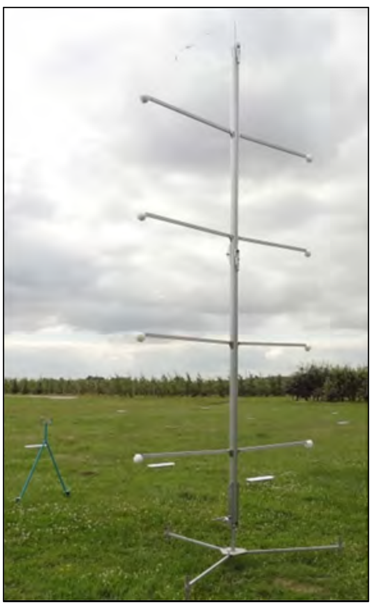

Figure 2. Airborne drift collectors on mast

Table 1
The wind velocity, relative humidity and temperature during the field tests

Parameters	Spray boom height (m)								
	0.35			0.5			0.75		
Liquid pressure (MPa)	0.15	0.3	0.5	0.15	0.3	0.5	0.15	0.3	0.5
Wind speed ($m\cdot s^{-1}$)	2.6	3.0	3.0	1.2	2.1	2.7	1.0	2.4	2.3
Relative humidity (%)	50	49	44	54	40.5	42	57.8	39.5	38.4
Air temperature (ºC)	30	24.3	24.3	29.2	25.3	25.5	27.1	26	26.9

Research results

Table 1 presents data on meteorological conditions during the test treatments and figures 3, 4, 5 and 6 show the graphs of drift profiles representing the distribution of airborne drift. Regardless the height of spray boom, the lowest airborne drift was obtained for pressure of 0.15 MPa (Fig. 6).

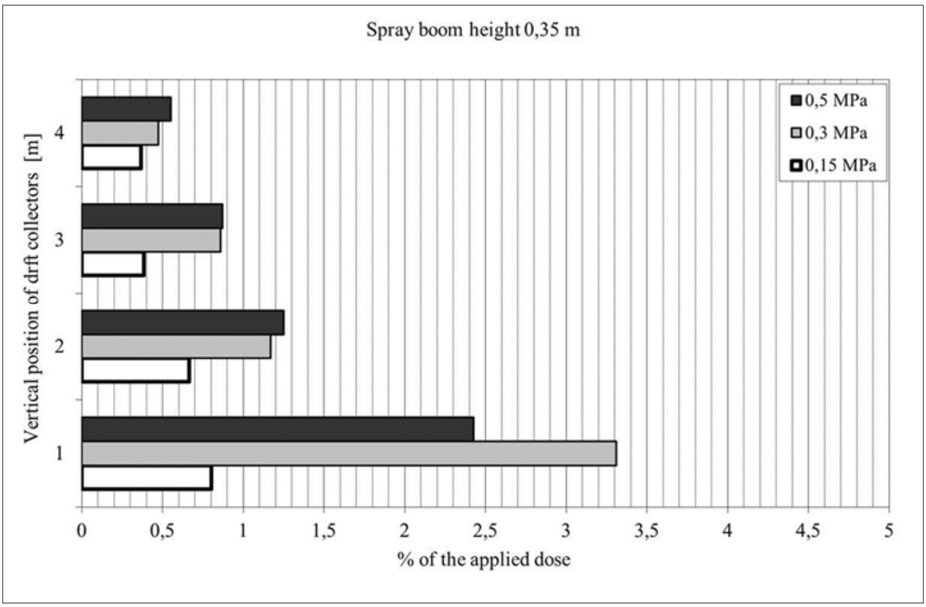

Figure 3. Airborne drift profile for spray boom height 0.35 m

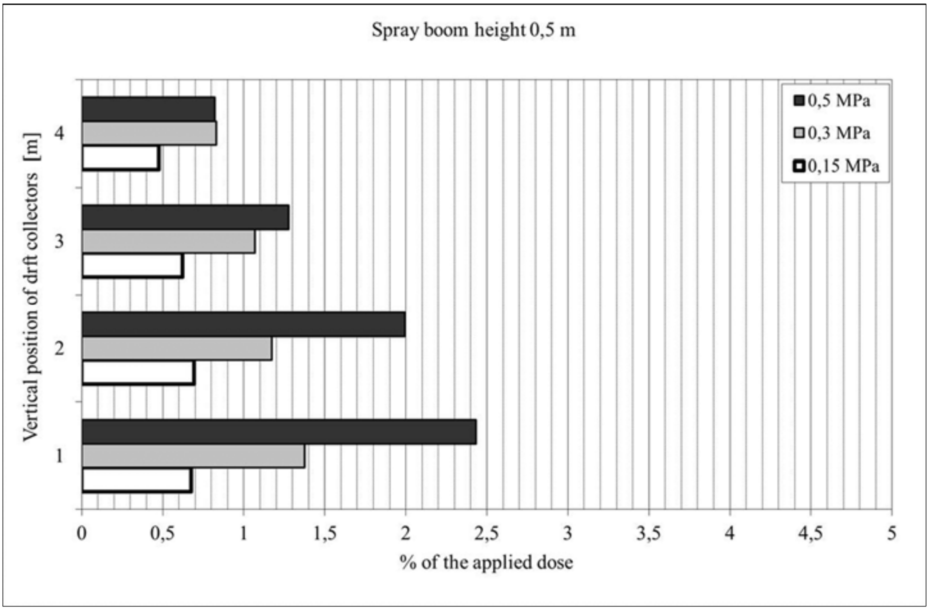

Figure 4. Airborne drift profile for spray boom height 0.5 m

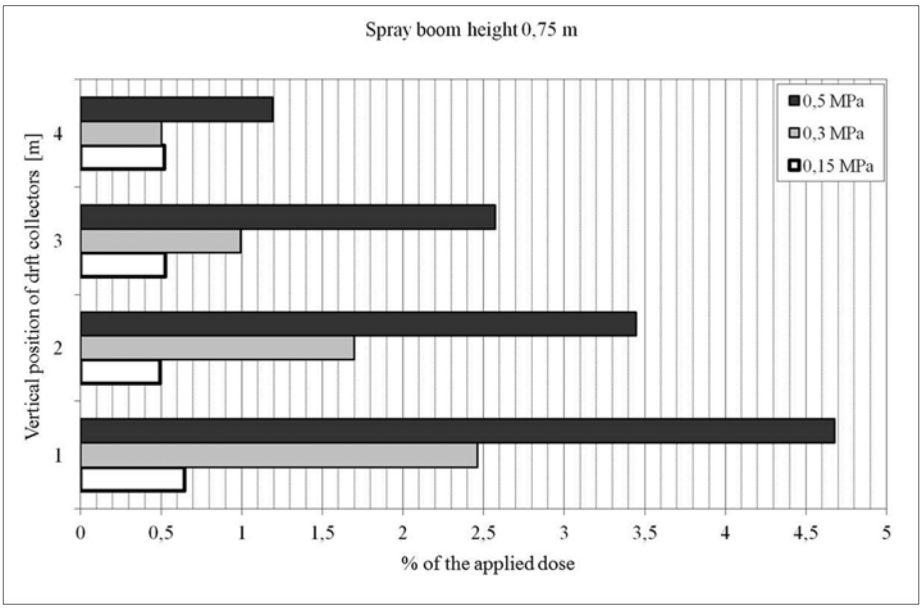

Figure 5. Airborne drift profile for spray boom height 0.75 m

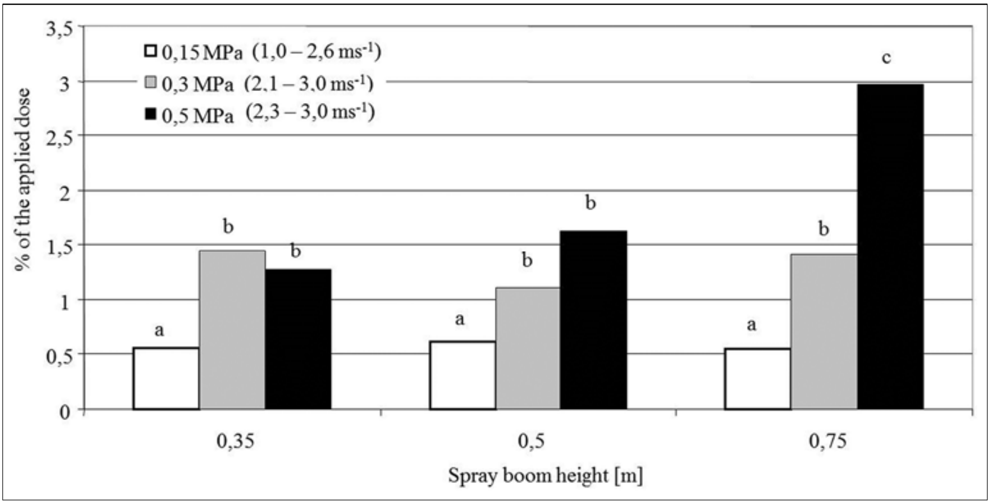

Figure 6. Total airborne drift (average values followed by the same letters do not differ significantly according to Duncan's Test, p=0.05)

Reduction of fraction of spray droplets smaller than 100 µm by decreasing of pressure in the sprayer liquid system to 0.15 MPa caused reduction of airborne drift almost by 50% in comparison to a standard spraying technique (height of a spray boom 0.5 m and pressure of 0.3 MPa). For this low pressure and all heights of the spray boom the drift measured on particular heights of samplers location was lower than that obtained at pressures of 0.3 and 0.5 MPa (Fig. 3, 4 and 5). Despite the expectations for the standard height (0.5 m) and the lowered height (0.35m) of a spray boom no significant differences of airborne drift were observed at pressures of 0.3 and 0.5 MPa. The spray boom raised to 0.75 m at the pressure of 0.3 MPa also had no significant effect on spray airborne drif. Only the increase of pressure to 0.5 MPa for the highest boom level caused a significant increase of airborne drift. In comparison to the standard spraying technique, airborne drift increased then by 270%. Regardless the height of samplers location, the increase of pressure to 0.5 MPa caused a considerable increase of drift in comparison to lower pressures. In case the samplers were placed at the height of 1 and 2 meters over the ground, airborne drift was almost two times higher for the pressure of 0.3 MPa and seven times higher for the pressure of 0.15 MPa (Fig. 5). For samplers location of 3 meters the drift was 2.5 times higher for pressure of 0.3 MPa and 5 times higher for pressure of 0.15 MPa, whereas for location of samplers at the height of 4 meters, 2.5 times higher than for two remaining pressures. Moreover, according to expectations, along with the increase of samplers' location, reduction of airborne drift for all combinations of the spray boom control and use of working pressures was reported.

Conclusions

1. Reduction of pressure in the liquid system of a sprayer to 0.15 MPa caused the spray airborne drift reduction by 50% in comparison to the standard technique (height of a spray boom 0.5 m and pressure of 0.3 MPa) regardless the height of spray boom.
2. Raising the height of spray boom up to 0.75 m and the liquid pressure to 0.5 MPa increased airborne drift by 270 % with reference to a standard spraying technique.
3. The high spray boom and high pressure resulted in a considerable increase of airborne drift on all measured heights.

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WPŁYW PARAMETRÓW ROBOCZYCH OPRYSKIWACZA POLOWEGO NA ZNOSZENIE POWIETRZNE

Streszczenie. Celem prezentowanych badań było określenie wpływu wysokości belki polowej i ciśnienia roboczego na znoszenie powietrzne cieczy użytkowej. W badaniach zastosowano opryskiwacz zawieszany, wyposażony w standardową belkę polową o szerokości roboczej 12 m i rozpylacze Lechler LU 120-03. Zabiegi opryskiwania prowadzono na odcinku testowym o długości 60 m i szerokości roboczej opryskiwacza ze stałą prędkością roboczą 6,0 km·h^{-1}. Dla każdej kombinacji wysokości ustawienia belki polowej (0,35; 0,5; 0,75 m) i ciśnienia roboczego (0,15; 0,3; 0,5 MPa) wykonano 5 przejazdów odcinka testowego nanosząc znacznik fluorescencyjny. Naniesienie znacznika oceniane było na próbnikach rozmieszczanych na masztach o wysokości 4 m. Wyniki badań potwierdzają istotny wpływ wysokości pracy belki i ciśnienia cieczy użytkowej na znoszenie powietrzne. Najmniejsze znoszenie powietrzne uzyskano dla ciśnienia 0,15 MPa i to niezależnie od wysokości ustawienia prowadzonej belki polowej. W porównaniu ze standardową techniką opryskiwania (wysokość belki 0,5 m ciśnienie 0,3 MPa) uzyskano redukcję znoszenia powietrznego o 50%. Nadmierna wysokość prowadzenia belki polowej 0,75 m i wysokie ciśnienie 0,5 MPa spowodowało wzrost znoszenia powietrznego o 270%.

Słowa kluczowe: znoszenie powietrzne, belka polowa, rozpylacze, ciśnienie cieczy

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STABILIZATION OF SUCTION PRESSURE IN THE CONCEPTUAL MILKING UNIT

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ABSTRACT

The objective of the paper was to verify the structure of the system for regulation and stabilization of absolute pressure, which supplies the autonomous milking unit. The described milking unit constitutes a modern technical solution which enables separation of suction pressure from the transporting one; moreover it enables measurement of the volumetric intensity of milk outflow from the cow udder quarter. The scope of the paper included: construction of the pneumatic supply system of the milking machine, development of the concept of control system, programming a PLC controller for the accepted control algorithm (basing on the previous scientific research of authors) and verification of the system operation on the laboratory stand. The main element of the control system is a microprocessor controller, where an algorithm of suction pressure control was implemented with the use of fuzzy logic; all calculations used for controlling this size are executed there. Results of the experimental research allowed a positive assessment of the described technical solution. The structure needs to be verified in milking conditions, however, research works emphasised positive effects with regard to stabilization of pressure supplied under a teat.

Introduction

Fluctuations of pressure in a teat chamber are among main problems which occur in the mechanized cow milking (Ambord and Bruckaier, 2010). Its uncontrolled changes result in health problems of cow udders and as a consequence in reduction of the milking capacity (Wiercioch et al., 2011). The research works, which were carried out show necessity of controlling suction pressure in the function of mass intensity of milk outflow for particular quarters independently (Ipema and Hogewerf, 2008; Juszka et al., 2011b; Zaninelli and Tangorra, 2006). Correlation of those two dynamically changing parameters and additionally decrease of suction pressure at a high intensity of milk outflow from the quarter of cow udder will affect better blood supply to a teat of a cow udder (Rasmussen, 1993).

Scientific works include solutions which consist in stabilization of suction pressure directed to a teat chamber. A solution patented by Gedymin (2006) which is characterised by a gum division operating as a membrane which suppresses pressure fluctuations in a cluster is an example of such a mechanical system of pressure stabilization in a milking unit cluster. A method for partial solution to the problem consists in separation of suction pressure from the pressure which transports milk in a pipeline (Ordolff, 2001). Solutions of this type were suggested, inter alia, in the form of a cluster with a separate transport of milk and air in Kupczyk's paper (1990) and an autonomous milking unit in the paper by Juszka et al, (2011a). When considering air flows in a cluster and changes in volume, one may notice that the change of the teat chamber capacity, which results from the teat gum work, causes that air is pressed to a milk chamber of a cluster. This phenomenon results from activity of combined vessels, which constitute those two chambers. During milking, capacity of those chambers and pressure inside may change (Ipema and Hogewerf, 2008). The manner of control and stabilization of under pressure, presented in this article, constitutes an extension of such a system of combined vessels with an accumulator with a microprocessor control and stabilization of suction pressure.

The objective of the paper was to develop a system for control and stabilization of absolute suction pressure, which supplies a column of an autonomous milking machine cluster.

The scope of work included:

- construction of the measuring and control system,
- programming PLC controller acc. to an algorithm which includes fussy logic, which describes the relation of absolute pressure with a momentary volumetric intensity of milk outflow from the quarter of a cow udder,
- verification tests performed at a laboratory milking stand.

The system of control of an innovative milking machine

The object of the research was a conceptual autonomous milking machine, presented in figure 1, where separated suction and transporting pressure was applied. The structure of this device is protected by a patent. One section which operates a quarter of a cow udder is visible, it has two containers filled in in turns. In the presented milking machine two control systems performed by one PLC controller can be distinguished. One is related to controlling milk and air inflow through electric clamp valves mounted on milking and air conduits. The second one controls suction pressure, which is provided to the teat chamber of a milking cup. It is recommended to correlate the value of this pressure with milk outflow to a given milking teat, moreover, suction pressure which delivers milk to a pipeline installation (with a higher value) may not cause changes of teat pressure.

The described system of automatic control of absolute pressure in a teat chamber of a milking cup was created as a result of modelling works carried out in Matlab-Simulink software (Juszka et al., 2011a; Lis et al., 2010). A method of fast prototyping control system was used in the process of modelling. Positive results of computer simulation allowed adjustment of particular elements of this system structure. A block scheme presented in figure 2 shows an algorithm of activity of the control and stabilization system of this pressure.

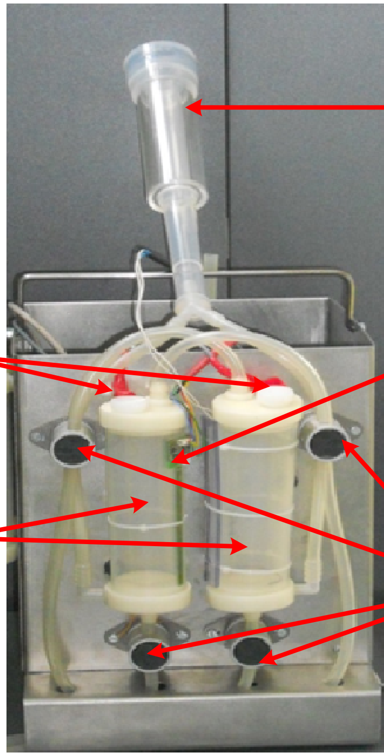

Figure 1. Autonomous milking unit

The system of automatic control of absolute pressure in the teat chamber of the milking cup is equipped with two measuring systems. The first of them measures the value of suction pressure p_s of air which is present in the milking machine, from where it directly gets to a teat chamber. The second one measures the level of milk in the columns of a milking unit and then calculation of the value of the volumetric stream of the milk outflow from a teat of a cow udder is carried out Q_V in a programmable logic controller PLC. It constitutes an input size for the control system.

Based on the signal, *Fuzzy Logic Controller* computes the set value of suction pressure for the milking machine p_{sz} (Tomasik et al., 2011). This value is comparable to the signal from the pressure sensor p_s, a computed error of control gets to the PID controller, which through control of a proportional valve (Fig.3) brings the value of pressure p_s closer to the set value $p_{sz.}$

The main element of the control and stabilization of air pressure is a container which suppresses fluctuations of absolute pressure (Fig. 3). It is equipped with connection pipes for connection of conduits which deliver: absolute pressure from a vacuum pump and atmospheric pressure through a proportional valve.

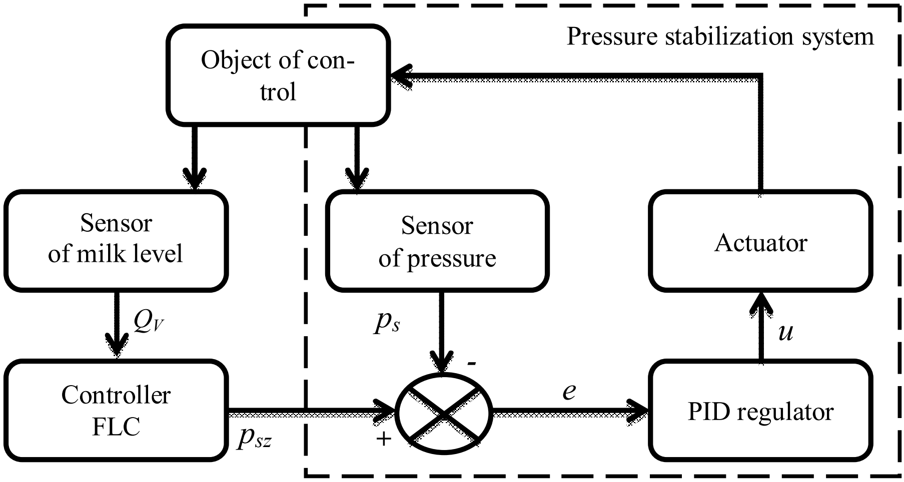

Figure 2. Schematic representation of the autonomous control system

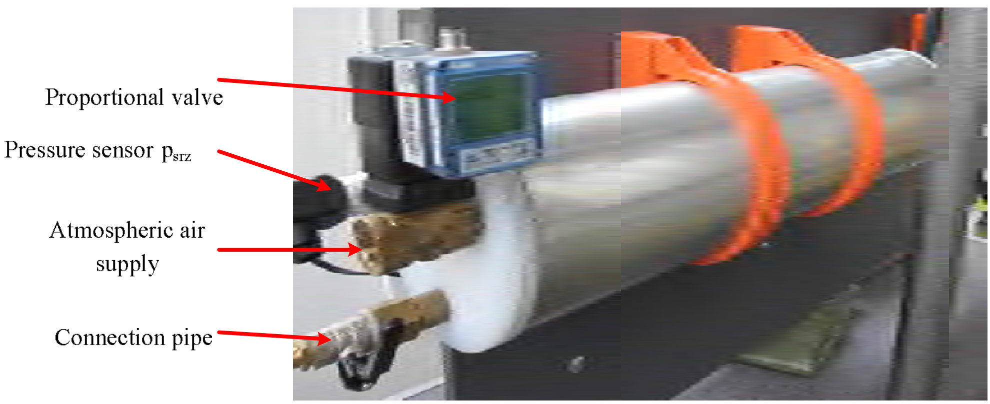

Figure 3. Container of suction pressure which supplies milking machine

Realization of the controlling algorithm with the size of suction pressure is programmed in the function of volumetric intensity of milk outflow from a teat of a cow udder. This size is computed by a functional block in the PLC controller. The input information for this block is the level l (mm) of milk in a chamber, measured by a sensor for each chamber independently. A cross-section of a chamber is fixed for the entire measurement scope (1):

$$Q_V = \frac{dV}{dt} \; (m^3 \cdot s^{-1}) \tag{1}$$

where:

Q_V	–	volumetric flow intensity, ($m^3 \cdot s^{-1}$)
V	–	present capacity (m^3) computed as a product of cross section area of a chamber s and levels of milk l
t	–	time, (s)

Moreover, in the PLC controller a functional block of fuzzy logic controller FLC and a functional block of the PID controller were programmed. Furthermore, a presented system of pressure stabilization was reflected in the form of visualization on the PLC controller, which enabled observation of its operation and registration of data for analysis (fig. 4).

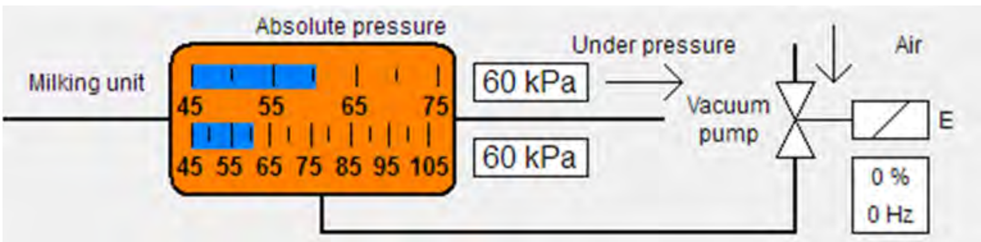

Figure 4. Visualization of operation of pressure system from the control programme

Analysis of operation of the pressure stabilization system in the conceptual milking machine

Graphs, which picture operation of the control and stabilization system of absolute pressure supplied to a cluster, were presented in Figures 5-8. The value of pressure was registered with the measurement card Advantech PCI-1711 with resolution of a converter of 12 bits. For measurement of suction pressure in the teat chamber the sensor of absolute pressure with precision of 0.25% was used. The system was tested in laboratory conditions. Distilled water was used instead of milk. The results of measurement of pressure, registered by a measurement card, were transferred to DAsyLab software, where they were registered. This program enabled scaling pressure sensors only in bar units, suction pressure is scaled as under pressure. In a milk pipeline, there was a transport pressure of 0.55 bar size (under pressure 55 kPa).

Figure 5 presents a dynamic characteristic of suction pressure changes before starting the liquid flow through a milking cup and a cluster column. It is a pressure, which directly affects teats of a cow udder during milking at the use of an autonomous milking unit. A recommended value of this absolute pressure should be within 0.35 bar to 0.47 bar. Analysing the amplitude of changes, one may notice, that the system is in a determined state.

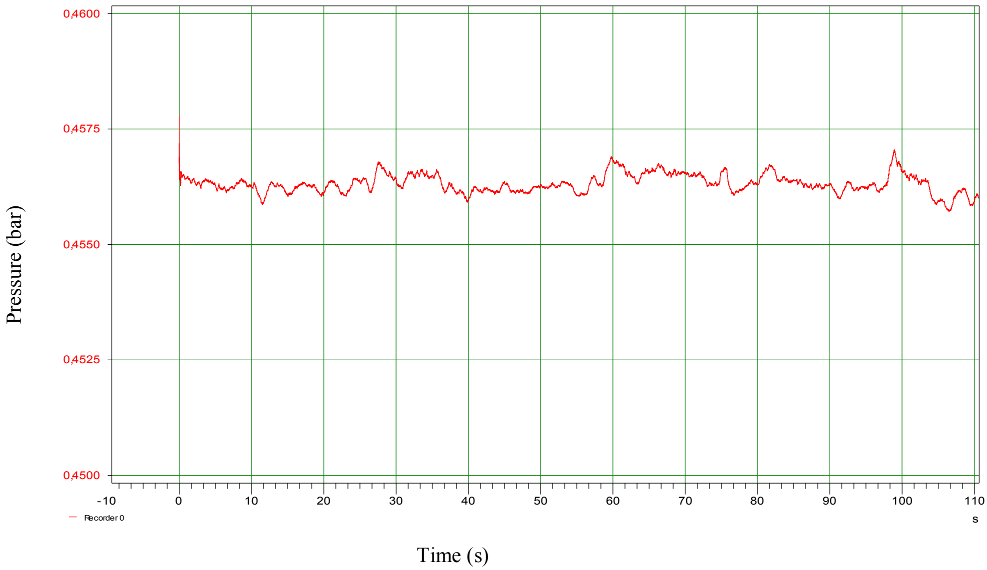

Figure 5. Changes of under pressure in teat chamber of milking cup before the liquid flow is initiated

The next stage in the research was introducing milk replacing liquid to circulation. Three basic values of liquid flow were assumed: 0.236 $dm^3 \cdot min^{-1}$, 0.850 $dm^3 \cdot min^{-1}$ and 1.625 $dm^3 \cdot min^{-1}$. The last value corresponds to the maximum flow, possible only for high productive diary cows. The values were selected, taking into consideration suggestion presented in scientific works (Ipema and Hogewerf, 2008). It should be noticed that they refer to one quarter of an udder, since one column of a milking unit includes only one quarter. Total volumetric intensity of outflow for a cow may be within 4 to 9 $dm^3 \cdot min^{-1}$.

Figure 6 reflects a characteristic of suction pressure for flow of 0.236 $dm^3 \cdot min^{-1}$. Impulse changes of pressure during switching between chambers can be reported. A clamp valve closes inflow of milk replacing liquid to one chamber, the other one opens inflow of liquid to the second chamber. The first chamber is emptied in this time with a higher suction pressure in order to speed up this process. As a result of filling in chambers, suction pressure decreased from 0.45 bar to 0.42 bar.

Characteristic of suction pressure for the liquid flow of the value of 0.850 $dm^3 \cdot min^{-1}$ is presented in figure 7. Varied pressures for each chamber were reported, values differed at the average by 0.02 bar. Cluster chambers were supplied as in all measurements with pressure of 0.45 bar.

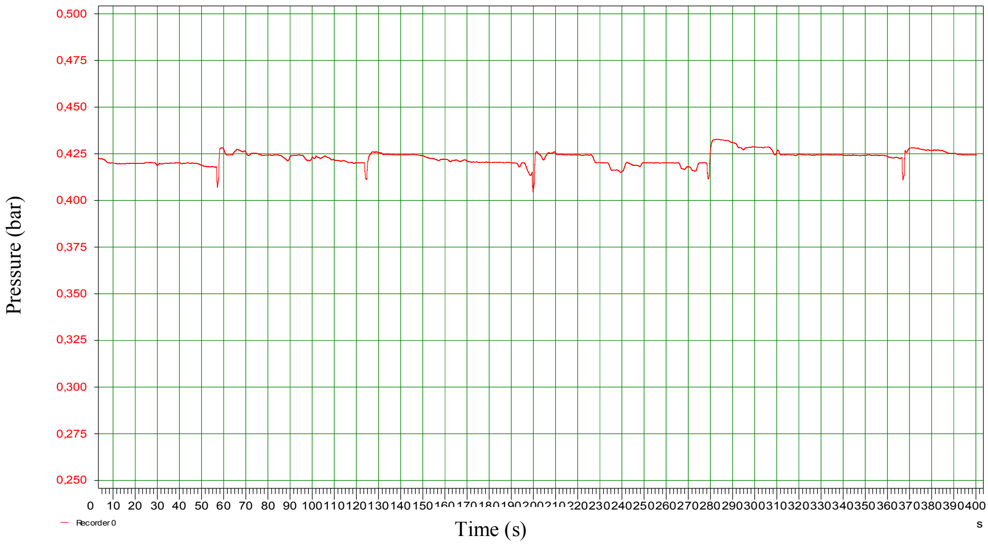

Figure 6. Changes of pressure in teat chamber of milking cup at the liquid flow of 0.236 dm^3·min^{-1}

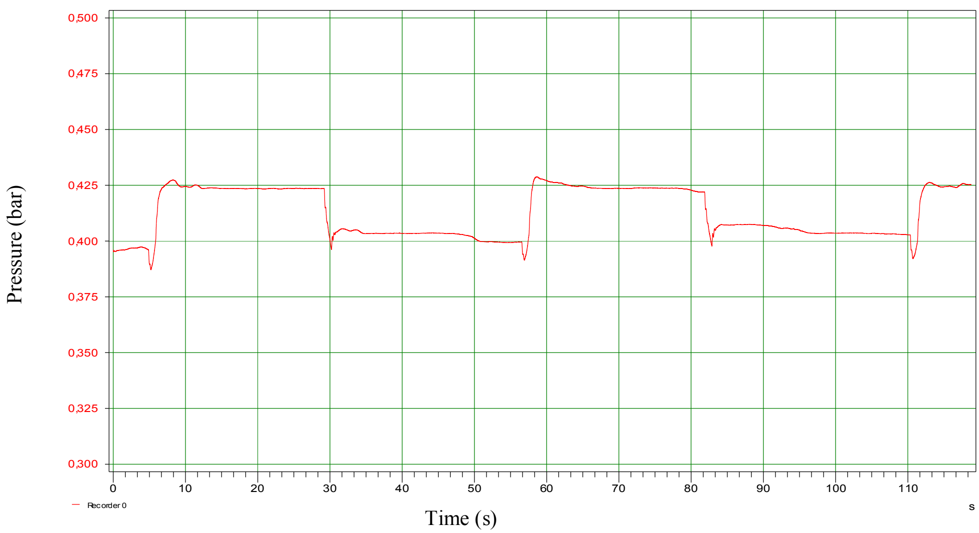

Figure 7. Changes of pressure in teat chamber of milking cup at the liquid flow of 0.850 dm^3·min^{-1}

In the last series of tests presented in figure 8, measurement of suction pressure was carried out for the flow of 1.625 $dm^3 \cdot min^{-1}$. As it was mentioned before it is a border flow reported in case of highly productive dairy cows. As in the above presented measurement a difference in pressures for particular chambers was reported, it was at the average of 0.03 bar. At such a high intensity of liquid flow a further decrease of suction pressure was reported to 0.37 bar.

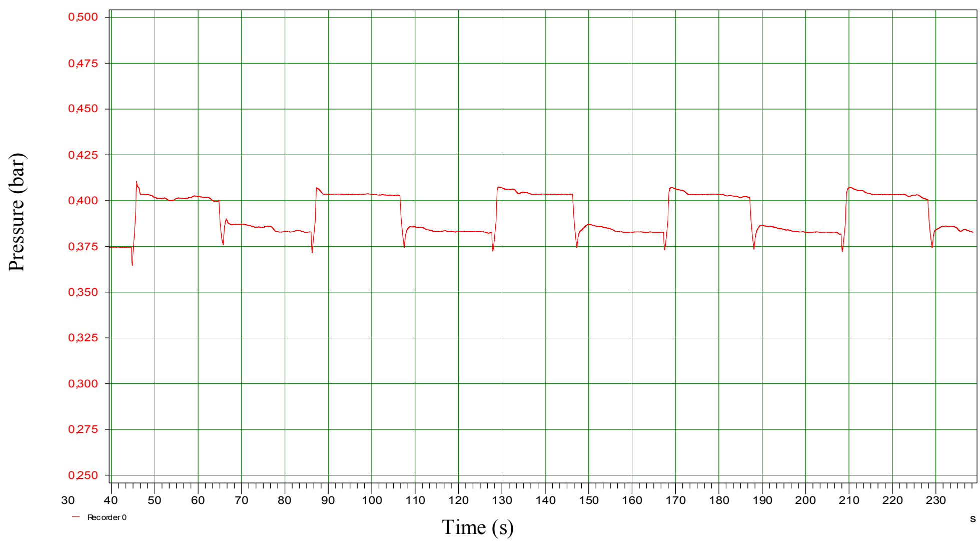

Figure 8. Changes of pressure in teat chamber of milking cup at the liquid flow of 1.625 $dm^3 \cdot min^{-1}$

Conclusions

1. The application, programmed with fuzzy logic methods, which carries out the function of the suction pressure programmer allows correlation of the milk flow intensity from a cow teat with the suction pressure, which is in a teat chamber of a milking cup. Such a controlling module does not influence the extension of the programming cycle of PLC controller XC-101.
2. Registered drops of suction pressure are so low that they will not negatively influence the cow udders.
3. The increased pressure used for transport of milk replacing liquid did not affect the suction pressure fluctuations at a lower flow intensity. Since, the chamber was emptied faster than the other was filled in, the suction pressure was stabilizing around the set value.

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STABILIZACJA CIŚNIENIA SSĄCEGO W KONCEPCYJNYM APARACIE UDOJOWYM

Streszczenie. Celem pracy była weryfikacja konstrukcji układu regulacji i stabilizacji ciśnienia bezwzględnego, zasilającego autonomiczny aparat udojowy. Opisywany aparat udojowy stanowi nowatorskie rozwiązanie techniczne, umożliwiające odseparowanie ciśnienia ssącego od transportowego, ponadto umożliwia pomiar objętościowego natężenia wypływu mleka z ćwiartki wymienia krowy. Zakres pracy obejmował: budowę pneumatycznego układu zasilającego aparat udojowy, opracowanie koncepcji systemu sterowania, zaprogramowanie sterownika PLC dla przyjętego algorytmu sterowania (bazującego na wcześniejszych badaniach naukowych autorów) oraz weryfikację pracy systemu na stanowisku laboratoryjnym. Głównym elementem układu regulacji jest sterownik mikroprocesorowy, w którym zaimplementowano algorytm regulacji ciśnienia ssącego, korzystając z logiki rozmytej; w nim realizowane są wszystkie obliczenia wykorzystane na użytek sterowania tą wielkością. Wyniki przeprowadzonych badań doświadczalnych pozwoliły na pozytywną ocenę opisywanego rozwiązania technicznego. Konstrukcja wymaga weryfikacji w warunkach doju, jednak prace badawcze uwidoczniły pozytywne efekty w zakresie stabilizacji ciśnienia dostarczanego pod strzyk.

Słowa kluczowe: aparat udojowy, ciśnienie ssące, regulacja automatyczna

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TECHNICAL AND ECONOMICAL ASPECTS OF BIOGAS PRODUCTION FROM AGRICULTURAL SOURCES INCLUDING POLISH CONDITIONS

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ABSTRACT

The paper aimed at investigating the influence of technical and economical aspects of biogas production from agricultural sources including the Polish conditions, which affacted implementation of the Directive 2009/28/EC of the European Parliament and the Council on the promotion of the use of energy from renewable sources. The investigations included the analysis of biochemical and technical problems of biogas production and the development of renewable energy resources in Poland. Operational tests (conducted 2011-2012) of a small biogas plant, with the total capacity of two reactors of 411 cubic meters, have enabled determination of the electricity production cost amounting to 113.76 PLN·MWh^{-1} and the heat production costs amounting to 206.06 PLN·MWh^{-1}. The construction cost of the biogas plant was 1100 PLN per cubic meter. The exploitation costs of biogas plant were – 42 450 PLN·year^{-1} as the cumulative costs of: the annual cost of installation maintenance 27 000 PLN·year^{-1} and the cost of use of the biogas plant – 5 450 PLN·year^{-1}. The calculated profit from the sale of the produced electricity was 100 622 PLN·year^{-1}. The calculation has been prepared in accordance with the prices in Poland in 2011-2012.

Introduction

Agricultural biogas – fuel gas produced by anaerobic digestion of agricultural raw materials, agricultural products, liquid or solid livestock manure, by-products or residues from the processing of agricultural products or forest biomass, with exception of gas from sewage treatment plants and waste landfills (according to the Journal of Laws, 1997 No. 54, item. 348). Implementation of the Directive 2009/28/EC of the European Parliament and the Council (23rd April 2009) on the promotion of the use of energy from renewable sources has contributed to the increased interest in the development of renewable energy sources, including obtaining biogas from agricultural sources. On 13th July 2010 the Council of Ministers approved a document entitled "Guidelines for biogas development in Poland in 2010-2020", which assumes construction of biogas plants in each Polish community.

Publications of various research institutes and technical centers, including the Institute of Technology and Life Science, Branch in Warsaw and Poznan has become the answer to the growing demand for expertise in the area of biogas (Romaniuk et al., 2011; Romaniuk et al., 2012 a,b; Głaszczka et al., 2010; Myczko et al., 2011).

Objective of the studies and methodology

The aim of the study was to present technical and economical aspects of biogas production from agricultural sources including Polish conditions, having an impact on implementation of the Directive 2009/28/EC of the European Parliament and the Council on the promotion of the use of energy from renewable sources.

The scope of work included: the analysis of biochemical and technical problems of biogas production; the development of renewable energy resources in Poland (in particular the study on the increase of the number of biogas stations); the economic balance of biogas station.

Investigations of agricultural biogas plant located at a private farm in Studzionka village (Lubusz voivodeship) were done according to the methodology of the Institute of Technology and Life Sciences presented by Romaniuk et al. (2011, 2012b).

The total exploitation costs *(C_e)* were specified according to the formula No. (1) – (Romaniuk et al., 2011, 2012b):

$$C_e = C_{main} + C_{use} \quad (\text{PLN}\cdot\text{year}^{-1}) \tag{1}$$

where:

C_{main} – the annual cost of installation maintenance, ($\text{PLN}\cdot\text{year}^{-1}$)
C_{use} – cost of use of the biogas plant, ($\text{PLN}\cdot\text{year}^{-1}$)

Unit exploitation cost c_{ej} is:

$$c_{ej} = \frac{C_{main} + C_{use}}{V} \quad (\text{PLN}\cdot\text{m}^{-3}) \tag{2}$$

where:

V – amount of produced biogas in normal conditions, ($\text{m}^3\cdot\text{year}^{-3}$).

Biogas station research has been carried out in the period of 2011-2012. Costs and profits were provided according to 2011-2012 prices.

Biochemical and technological problems

The following factors are the main reasons of disturbances in the biogas production process of both a biochemical and technological nature (according to Schattauer and Weiland, 2006):

– Fermentation temperature can quickly drop by a few degrees. Temperature drop inhibits the activity of methane bacteria, because they can survive only in a strictly limited temperature range. Hydrolyzing bacteria and acetic acids are not as sensitive to temperature fluctuations and can survive at lower temperatures. For this reason, in the fermenter, acid accumulates (pH decline) especially when the substrate supply is not stopped. Therefore, to ensure the effective use of installation, fermentation temperatures must be regularly monitored. This phenomenon contributes to the inhibition of the process, if the temperature goes up at the same time. This problem particularly relates to the systems operating within thermophilic fermentation. Another factor influencing the formation of ammonia is primarily a dosage substrates containing significant amounts of protein into the fermentor. As a result significant quantities of ammonia nitrogen are released.

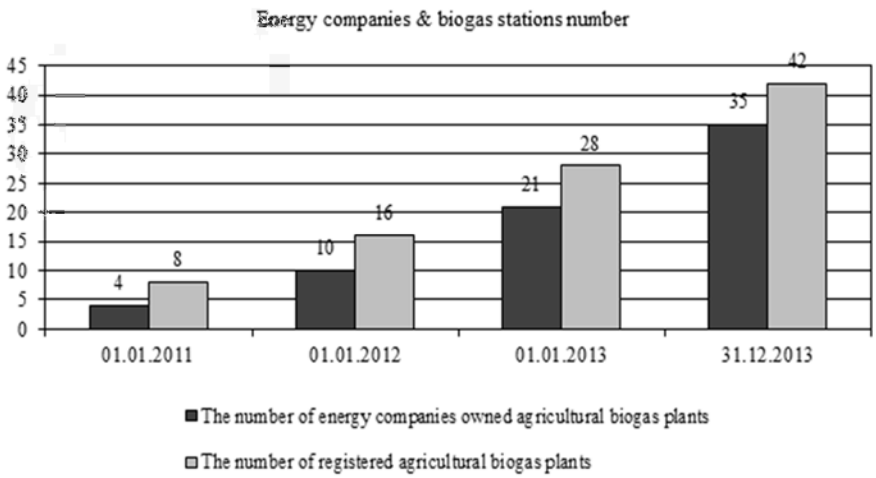
- Hydrogen sulphide – the concentration of H_2S released in the reactor increases with the decrease of pH value, and increases with the temperature growth.
- Faults in the substrate dosing - biogas plants inoculation is done in most cases, with cattle liquid manure, because this substrate has a suitable bacteria concentration. During the start-up phase of biogas plants, it is important that the substrate serves as a constant component as possible allowing bacteria to develop constantly. It is also important that the amount of substrate is provided in small doses of methane bacteria to give sufficient time for growth.
- If loading of substrate to the digester is provided too fast, the process of methane bacteria development will be slowed down. As a result of the acidification process, which can take the entire volume of the digester, like intermediates formed in earlier stages of fermentation, cannot be further decomposed. Immediately after the start-up phase a normal use of the system begins.
- Hydraulic retention time (HRT) – residence time of the substrate in the system until replaced by a new material and is a direct measure of load fermented organic material. If short time activity occurs very quickly gas production will break down. In this case more bacteria can multiply at the same time by frequent exchanges of the substrate. In practice, you can not get the maximum production, so rather you should seek a compromise between the stability of the fermentation process and gas production.
- Influence of the substrate quality on the fermentation process – the use of residual feed or substrates at an advanced stage of decomposition can lead to a significant reduction in gas production and foam secretion.
- Pre-treatment of the substrate – better availability of organic matter to conduct biodegradation, and as a result – higher gas yield. It is necessary to remove not wanted matter, such as stones, wood, etc. Initial treatment by fragmentation in particular requires a substrate such as hay or crop residues.
- PH – if the fermenter gets more substrate with lower pH, it can lead to the inhibition of the methane fermentation process. In this case, before feeding the medium to the fermentor, it will be necessary to adjust the pH by adding alkali. Clear differences in pH between the content of the fermenter and the feed substrate also lead to strong foaming, as if CO_2 is released from the liquid.

Development of renewable energy resources in Poland

The aim of the development of renewable energy sources, including obtaining biogas, is the need to protect the environment, to diversify the local energy supply, support innovative technology solutions, create opportunities for regional development and new jobs. The so-called “climate package” implemented for Poland as an obligation to obtain a 15% share of RES in the structure of energy consumption by 2020. However, due to a high cost of investment in the process of investigation to increase the share of renewables in energy balance, it was necessary to take specific actions at the government level, to coordinate, develope support systems, which can guarantee their systematic development.

The Agricultural Market Agency gathers information about the activities of energy companies involved in the production of agricultural biogas. Registered entities are obliged to submit quarterly reports containing the following information:
- the type and amount of substrates used in the production of agricultural biogas,
- the amount of agricultural biogas produced, the amount of biogas introduced into the gas distribution network,
- the amount of heat and electricity generated from agricultural biogas cogeneration system.

The graph below shows the change in the number of entities included in the Polish register of agricultural biogas plants and the number of installations in the period of 2011-2013.



Source: author’s own calculation based on data of Agricultural Market Agency (ARR)

Figure 1. The number of energy companies and registered agricultural biogas plants in Poland

The produced agricultural biogas, after the necessary cleaning of unfavorable compounds, was used to produce electricity and heat. Table 1 below presents data on the level of production of agricultural biogas, electricity and heat from agricultural biogas in the above mentioned period.

Table 1
Amount of agricultural biogas, electricity and heat production in Poland in 2011-2013

Year	Agricultural biogas production (10^6 m^3)	The amount of electricity produced from agricultural biogas (GWh)	The amount of heat produced from agricultural biogas (GWh)
2011	36.65	73.43	82.63
2012	73.15	141.80	160.13
2013	112.38	227.88	249.06

Source: author's own calculation based on data of Agricultural Market Agency, www.arr.gov.pl

Energy production from biogas in Poland and the European Union

The following tables 2 and 3 give the level of production of biogas divided into categories in the European Union and the volume of electricity production.

Table 2
Energy production from biogas in the EU in years 2010-2011(ktoe)

Country	Years							
	2010				2011			
	Landfill gas	Gas from sewage treatment plants	Biogas remaining from agri-culture	Total	Landfill gas	Gas from sewage treatment plants	Biogas re-maining from agriculture	Total
Germany	232.50	402.6	6034.5	6669.6	149.0	504.2	4414.2	5067.6
UK	1492.6	256.0	0.0	1750.6	1482.4	282.4	0.0	1764.8
Italy	349.6	8.1	149.8	507.5	755.6	16.2	323.9	1095.7
France	236.7	44.1	53.2	334.0	249.7	41.9	58.0	349.6
NL	36.7	50.2	206.5	293.4	31.5	51.5	208.3	291.3
CZ	29.5	35.9	111.3	176.7	31.8	38.8	179.9	249.6
Spain	119.6	12.4	66.7	198.7	148.1	15.3	82.6	246.0
Austria	5.1	22.3	144.2	171.6	4.3	164	138.8	159.5
Poland	43.3	63.3	8.0	114.6	47.5	67.8	20.1	135.4
Belgium	41.9	14.6	70.9	127.4	41.9	14.6	70.9	127.4
Sweden	35.7	60.7	14.8	111.2	12.4	68.9	37.9	119.3
Denmark	8.1	20.1	74.0	102.2	5.2	19.6	73.2	98.1
Greece	51.7	15.0	1.0	67.7	55.4	16.1	1.4	72.8
Ireland	44.2	9.6	4.6	58.4	43.8	8.2	5.6	57.6
Slovakia	0.8	9.5	1.8	12.2	3.0	13.6	29.3	45.8
Portugal	28.2	1.7	0.8	30.7	42.3	1.8	0.9	45.0
Finland	22.7	13.2	4.5	40.4	23.9	13.4	4.8	42.1
Slovenia	7.7	2.8	19.9	30.4	7.1	2.7	26.2	36.0
Hungary	2.6	12.3	19.3	34.2	7.3	6.4	15.5	29.1
Latvia	7.9	3.3	2.2	13.3	7.8	2.4	11.8	22.0
Luxemb.	0.1	1.2	11.7	13.0	0.1	1.4	11.3	12.8
Lithuania	2.0	3.0	5.0	10.0	5.9	3.1	2.1	11.1
Estonia	2.7	1.1	0.0	3.7	2.2	1.1	0.0	3.3
Romania	0.0	0.0	3.0	3.0	0.0	0.0	3.0	3.0
Cyprus	0.0	0.0	1.0	1.0	0.0	0.0	1.0	1.0
Total	2801.7	1065.0	7008.8	10875.4	3157.9	1298.0	5719.3	10085.8

Source: EurObservER, 2012

Table 3
Production of electricity from biogas in the EU in years 2010-2011 (GWh)

Year	2010			2011		
Country	Plants producing only electricity	Electric energy from cogeneration (CHP)	Total	Plants producing only electricity	Electric energy from cogeneration (CHP)	Total
Germany	14847.0	1358.0	16205.0	10935.0	8491.0	19426.0
UK	5137.0	575.0	5712.0	5098.0	637.0	5735.0
Italy	1451.2	602.9	2054.1	1868.5	1536.2	3404.7
France	756.0	297.0	1053.0	780.0	337.0	1117.0
Netherlands	82.0	946.0	1028.0	69.0	958.0	1027.0
Spain	536.0	117.0	653.0	709.0	166.0	875.0
Czech Rep.	361.0	275.0	636.0	535.0	394.0	929.0
Austria	603.0	45.0	648.0	555.0	70.0	625.0
Belgium	149.0	417.0	566.0	158.0	442.0	600.0
Poland	0.0	398.4	398.4	0.0	430.0	430.0
Denmark	1.0	352.0	353.0	10	342.0	343.0
Ireland	184.0	22.0	206.0	181.0	22.0	203.0
Greece	190.5	31.4	221.9	37.6	161.7	199.3
Hungary	75.0	21.0	96.0	128.0	55.0	183.0
Portugal	90.0	11.0	101.0	149.0	11.0	160.0
Slovenia	7.2	90.2	97.4	5.7	121.0	126.7
Slovakia	1.0	21.0	22.0	39.0	74.0	113.0
Latvia	5.9	50.8	56.7	0.0	105.3	105.3
Finland	51.5	37.8	89.2	53.6	39.4	93.0
Luxemburg	0.0	55.9	55.9	0.0	55.3	55.3
Lithuania	0.0	31.0	31.0	0.0	37.0	37.0
Sweden	0.0	36.4	36.4	0.0	33.0	33.0
Romania	0.0	1.0	1.0	0.0	19.1	19.1
Estonia	0.0	10.2	10.2	0.0	17.0	17.0
Total	24528.2	5803.0	30331.2	21302,4	14554.1	35856.4

Source: EurObservER, 2012

Legal acts on renewable energy sources including biogas

Lack of coherence in the Polish legislation on renewable energy sources, in particular the absence of law on renewable energy sources, lower prices of certificates, are the main reasons of inhibition of biogas plants development in Poland. A biogas market leader – Germany – applied legal solutions that have become a model copied by other countries. The basis for payment of wages for RES entrepreneurs is the law for promoting renewable energy sources – "Gesetz für den Vorrang Erneuerbarer Energien" (Erneuerbare-Energien-Gesetz – EEG). The following Table 4 shows rates of 1 kWh of electricity from different sources.

Table 4
The financial support rate depending on biogas plant power

Type of source	Nominal biogas plant power	The rates for the acquired electricity from RES (1/100 € per 1 kWh)	German law reference
Landfill gas	up to 500 kW (inclusive) from 500 kW to 5 MW (incl)	8.60 5.89	§24 EEG
Gas from sewage treatment plants	up to 500 kW (incl) from 500kW to 5 MW (incl)	6.79 5.89	§25 EEG
Biogas remaining, eg. from agriculture	up to 1 MW (incl) from 1MW to 5 MW (incl) above 5 MW	6.84 4.93 3.98	§26 EEG
Biomass	up to 150 kW (incl) from 150 kW to 500 kW (incl) from 0.5 MW to 5 MW (incl) up to 20 MW (incl)	14.3 12.3 11.0 6.0	§27 EEG
Biogas generated from manure	max 75 kW*	25.0	§27b EEG

* Additional conditions:

- biomethane conversion into electricity is conducted on-site biogas production,
- installed power of biogas plant (total),
- manure is at least 80 % by mass.

Source: author's own calculation based on data of Erneuerbare-Energien-Gesetz, 2012

In countries that are leaders in the production of biogas, generally limited to 60% of the input of grain and corn, in the case of the sale price mechanism the FiT tariff is introduced (Feed-In Tariffs). Introduction of the feed-in tariffs system in Poland is provided by a government bill on renewable energy sources, which in accordance with the rules of the European Union (Directive of the European Parliament and the Council 2009/28 / EC of 23 April 2009 on the promotion of the use of energy from renewable sources) was enacted by the end of 2010, and was not implemented by Poland before the European Court of Justice.

The Polish government action may indicate the intention to promote micro and small biogas plants established on small farms to avoid biogas market monopolization by large companies. The advantage of the installation up to 0.5 MW is the fact that it is easier to transport substrates for the biogas plant. However, the greater the power of biogas, they can also use a lot of extra equipment, safety procedures concerning environmental protection and health, and use many types of wastes. They can also achieve the best financial results with the installed capacity in the range of 1-2 MW. The downside may be a need to transport substrates from a distance, and it should be stressed that the transport operation may be inconvenient for the local community.

Method of calculation of energy produced from biogas

The method of calculation of the amount of energy generated from biogas was provided by the Ministry of Economy on 18 October 2012 on the specific scope of obligations to obtain and submit for cancellation certificates of origin, the substitute fee, purchase of electricity and heat from renewable energy sources and the obligation to confirm the data on the amount of electricity generated from renewable energy sources (Journal of Laws, item 1229).

The manufacturing unit, which burns biomass or biogas together with other fuels and the energy produced from renewable energy sources are classified as a part of the electricity or heat corresponding to the share of the chemical energy in biomass or biogas fuel chemical energy consumed in the production of energy, calculated on the basis of the calorific value of the fuel, according to the formula (3):

$$EOZE = \frac{\sum_{i=1}^{n} MBiWBi}{\sum_{i=1}^{n} MBiWBi + \sum_{j=1}^{m} MKjWKj} E \tag{3}$$

where:

- E_{OZE} – the amount of electricity or heat from renewable energy sources, (MWh, GJ)
- E – the amount of electricity or heat produced in a generating unit, which combusts biomass or biogas together with other fuels, (MWh, GJ)
- M_{Bi} – amount of biomass or biogas, burned in the generating unit, (Mg)
- M_{Kj} – amount of fuel other than biomass or biogas combusted in the generating unit, (Mg)
- W_{Bi} – calorific value of biomass or biogas burned in a generating unit, ($MJ \cdot Mg^{-1}$)
- W_{Kj} – calorific value of fuel other than biomass or biogas combusted in the generating unit, ($MJ \cdot Mg^{-1}$)
- n – the number of types of biomass or biogas burned in a generating unit,
- m – the number of types of fuels other than biomass or biogas, burned in the generating unit.

Biogas quality parameters

The quality of biogas in Poland is standardized by the Regulation of the Ministry of Economy of 24th August 2011. On the detailed scope of the obligation to confirm the data on agricultural biogas produced introduced into the gas distribution network (Journal of Laws of 2011, no. 187, item 1117). In addition, the following quality parameters of agricultural biogas introduced into the gas distribution network have been established (Table 5 and 6).

Table 5
The quality parameters of agricultural biogas introduced into the gas distribution network

No.	Indicator	The limit value
1.	Hydrogen sulphide content	$7.0\ mg \cdot m^{-3}$
2.	Mercaptan sulphur content	$16.0\ mg \cdot m^{-3}$
3.	Total sulphur content	$40.0\ mg \cdot m^{-3}$
4.	The content of mercury vapor	$30.0\ \mu g \cdot m^{-3}$

No.	Indicator	The limit value
5.	The dew point temperature of water at the pressure of 5.5 mpa A) from 1 April to 30th September B) from 1 October to 31st March	 no more than +3.7 ˚C no more than – 5.0 ˚C
6.	Calorific value of agricultural biogas introduced into the natural gas transport network:	
	a) With a high content of methane group E of the Wobbe index in the range of 45.0 MJ·m^{-3} (incl) up to 54.0 MJ·m^{-3}	34.0 MJ·m^{-3}
	b) Nitrogen-rich, subgroup Lw, Wobbe index in the range of 37.5 MJ per cubic meter (incl) up to 45.0 MJ·m^{-3}	30.0 MJ·m^{-3}
	c) Nitrogen-rich, subgroup Ls, Wobbe index in the range of 32.5 MJ·m^{-3} (incl) up to 37.5 MJ·m^{-3}	26.0 MJ·m^{-3}
	d) Nitrogen-rich, subgroup Ln, Wobbe index in the range of 27.0 MJ·m^{-3} (incl) up to 32.5 MJ·m^{-3}	22.0 MJ·m^{-3}
	e) Nitrogen-rich, subgroup Lm, Wobbe index in the range of 23.0 MJ·m^{-3} (incl) up to 27.0 MJ·m^{-3}	18,0 MJ·m^{-3}

Source: author's own elaboration based on data of Polish Law 2011, no. 187, item 1117

Table 6

Terms of references for biogas production

Terms of reference for biogas	Parameter	
	Pressure	Temperature
Combustion process	101.325 kPa	298.15 K (25˚C)
Volume measurement	101.325 kPa	273.15 K (0˚C)

Source: author's own study based on data of Polish Law 2011, no. 187, item 1117

The amount of agricultural biogas production shall be recalculated into the equivalent amount of electricity generated in renewable energy sources, according to the equation (4):

$$E_{OZEekw} = \eta \sum_{i=m}^{n} (M_{bri} \times r_i) \tag{4}$$

where:

- $E_{OZE\ ekw}$ – the amount of electricity possible to be generated using renewable energy sources as an equivalent of biogas introduced into the gas distribution network, (MJ)
- n – the number of batches of agricultural biogas introduced into the gas distribution network,
- m – indication of next batch of agricultural biogas introduced into the gas distribution network,
- M_{bri} – number of agricultural biogas introduced into the gas distribution network in different parts of (m^3), with a specific calorific value measured using the measuring devices settlement,
- r_i – the real calorific value of a particular amount of agricultural biogas introduced into the gas distribution network, (MJ·m^{-3})
- η – reference efficiency value for separate electricity production unit consuming agricultural biogas, (η= 52.5%)

Results of investigations of biogas plant

Investigations of the agricultural biogas plant were carried out according to the methodology of the Institute of Technology and Life Sciences presented in the work: “The method of assessment of agricultural biogas plants” (Romaniuk et al., 2011). Biogas station research has been carried out in period 2011-2012 and is presented below (Table 7). Costs and profits were given according to 2011-2012 prices.

Table 7

Results obtained during the study of biogas plants in Studzionka village (Lubusz Voivodeship)

Parameters and results	Units	Values
Number of fermentation chambers	(-)	2
Total capacity of fermentation chambers of biogas plant	(m^3)	410
Investment cost of the whole installation	(PLN)	450 000
The cost of building - 1 m^3 of biogas plant	(PLN)	1 100
The amount of biogas produced per year	(m^3)	112 000
Calorific value of biogas	($MJ \cdot m^{-3}$)	20.75
The amount of electric energy produced from biogas	($MWh \cdot year^{-1}$)	212
The amount of heat produced from biogas	($MWh \cdot year^{-1}$)	246
The potential profit from the sale of produced electricity	($PLN \cdot year^{-1}$)	100 622
The market price of energy sold to the grid	($PLN \cdot MWh^{-1}$)	197.72
The market price of green certificates of origin	($PLN \cdot MWh^{-1}$)	273.73
The annual cost of maintaining installation C_{main}	($PLN \cdot year^{-1}$)	27 000
Cost of use of the biogas plant C_{use}	($PLN \cdot year^{-1}$)	15 450
The exploitation costs of biogas plant C_e	($PLN \cdot year^{-1}$)	42 450
The cost of electricity production in the installation	($PLN \cdot MWh^{-1}$)	86.2
The cost of heat production in the installation (In the calculation does not take into account 30% of the heat that is used to the biogas plant heating)	($PLN \cdot MWh^{-1}$)	156.13
Annual use of slurry and poultry manure for biogas production	(t)	1058.5
The cost of raw material	($PLN \cdot t^{-1}$)	10
Annual cost of raw material	(PLN)	10 585
The cost of electricity production	($PLN \cdot MWh^{-1}$)	113.76
The cost of heat production	($PLN \cdot MWh^{-1}$)	206.06

Conclusions

Based on the literature review and the research which was carried out, the following conclusions have been presented:

1. Biogas plants are the objects of stable energy, which when properly used with the technological regime, have a constant electrical performance and can be built to meet the demand for electricity. Biogas production is still a major part of the objectives of the National Action Plan for energy from renewable sources by 2020.
2. In Poland, it is warranted to build both agricultural biogas plants below 100 kW, as well as much larger installations. The final investment decision should result from a comprehensive account of the opportunities and needs.
3. Usage of agricultural biogas depends on many factors specific to location of each installation (distance from the grid, general and local demand for a particular source of energy).
4. Only the investor, not local administration representatives decide how to use the produced biogas (purification and delivery to the network, or conversion to electricity and / or heat).
5. National policies have the greatest influence on the development of renewable energy production in different countries of the European Union.
6. The lack of consistent rules, and especially delayed publication of the Renewable Energy Sources Law constitute an impediment for the development of agricultural biogas plants in Poland.
7. Operational tests of a small biogas plant with total capacity of the two reactors of 411 m^3 conducted in 2011-2012, have enabled determination of the actual electricity production cost - 113.76 $PLN \cdot MWh^{-1}$ and heat production costs - 206.06 $PLN \cdot MWh^{-1}$. The cost of building of 1 m^3 of biogas plant in the economic way was PLN 1100. The exploitation costs of the biogas plant was 42 450 $PLN \cdot year^{-1}$ as the cumulative costs: the annual cost of installation maintenance 27 000 $PLN \cdot year^{-1}$ and the cost of use of the biogas plant was 5 450 $PLN \cdot year^{-1}$.
8. The calculated profit from the sale of the produced electricity was 100 622 $PLN \cdot year^{-1}$.

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TECHNICZNE I EKONOMICZNE ASPEKTY PRODUKCJI BIOGAZU ZE ŹRÓDEŁ ROLNICZYCH Z UWZGLĘDNIENIEM POLSKICH WARUNKÓW

Streszczenie. Celem pracy były badania wpływu aspektów technicznych i ekonomicznych produkcji biogazu ze źródeł rolniczych z uwzględnieniem polskich warunków, mających wpływ na wdrożenie Dyrektywy 2009/28/EC Parlamentu Europejskiego i Rady na promocję użytkowania energii ze źródeł odnawialnych. Badania zawierały analizę problemów biochemicznych i technicznych oraz rozwój OZE w Polsce. Ponadto przedstawiono metodę kalkulacji ilości energii pozyskanej z biogazu oraz parametry jakościowe biogazu. Badania mikrobiogazowni rolniczej o łącznej pojemności komór fermentacyjnych 411 m^3 przeprowadzone w latach 2011-2012 w miejscowości Studzionka, woj. lubuskie, pozwoliły na uzyskanie następujących wyników: koszt produkcji energii elektrycznej 113,76 $PLN \cdot MWh^{-1}$ oraz produkcji ciepła 206.06 $PLN \cdot MWh^{-1}$. Jednostkowy koszt wybudowania instalacji wynosił 1100 $PLN \cdot m^{-3}$. Koszty eksploatacyjne kształtowały się na poziomie 42 450 $PLN \cdot rok^{-1}$ stanowiąc sumę kosztów: utrzymania 27000 $PLN \cdot rok^{-1}$ oraz kosztów użytkowania, które wynosiły 5450 $PLN \cdot rok^{-1}$. Dochód z tytułu sprzedaży energii oszacowano na poziomie 100622 $PLN \cdot rok^{-1}$. Rachunek ekonomiczny został sporządzony wg poziomu cen z lat 2011-2012**.**

Słowa kluczowe: odnawialne źródło energii, biogaz, elektryczność, ciepło, kogeneracja

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LEAN MANUFACTURING TOOLS IMPLEMENTATION AND ITS IMPACT ON THE COMPANY'S OPERATION IMPROVEMENT

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ABSTRACT

The aim of this article is to assess the impact of Lean Manufacturing tools on the work organization of two selected manufacturing company's departments. In order to determine the effectiveness of lean concept, organizational measures were presented. They were to improve production process efficiency of the analyzed departments. The following were analyzed: standardization of the selected worksites and time reduction of tasks performance in a production process during a changeover. The study confirmed a research hypothesis that implementation of Lean Manufacturing tools guarantees time and resources savings, improves company's operation, eliminates waste.

Introduction

The article discusses an important issue of implementation and operation of management systems in organizations on the example of Lean Manufacturing tools.

Based on the literature review (domestic and foreign), it was stated that nowadays there is an increasing universalization of concepts, ideas, models and management methods, and their movement between organizations. There is a possibility to choose a selected concept to achieve intended objectives. Those who are in charge of an organization, use tools developed by science, then modify them in such a way that they are the most effective for solving problems of a strategic or operational nature. In Poland introduction of the above mentioned solutions to improve an enterprise management process is not very popular. It means this is still an up-to – date field of activity.

The scientific goal of the paper is to analyze Lean Manufacturing - the concept of production that economically manages available resources. Using lean tools, an enterprise tends to lean production, eliminates redundant processes or insignificant for basic activities of the company's operations, creates a simplified and exhibiting greater efficiency organizational system. By implementation of lean concepts and instruments the following phenomena are noticeable: an increase of employees' motivation, development of a company's organizational culture, reduction of costs associated with production of finished products, reduction of stock levels and products' quality improvement.

This article analyzes the impact of the selected Lean Manufacturing tools for work organization of the studied production company (the owner did not give his consent to provide the company's name and the city). It was stated that satisfactory results will be achieved if few tools of lean manufacturing like: 5S, Kaizen, or SMED are to be implemented.

Lean Manufacturing concept - history and description

Lean Manufacturing is a "lean" management of an organization. Although the concept's name is derived from the United States, the idea was inspired by one of the Japanese companies that in the 50's of the 20th century was eliminating all signs of waste by improving the production management system (Wojciechowski, 2011).

The main aim of the concept was to increase efficiency of the lean production process through continuous elimination of waste (Hadaś and Cyplik, 2011; Mehta et al., 2012).

Waste (Japanese muda) is every activity that consumes resources and does not add value to a customer. Elimination of activities that are waste is the largest potential source of achievements for an enterprise (Marchwinski et al., 2008).

Seven types of waste can be distinguished: overproduction – excessive production of finished products, unnecessary movement - unnecessary movement of operators, which arises from insufficient control and mistakes concerning organization, awaiting – for equipment repair, material, quality control, previous operation, etc., unnecessary transport – logistics errors that cause unnecessary movement of goods, materials and components or lengthen transport routes, stock – maintaining stock of finished goods in a company warehouses or at the production floor, defects – defects of design, product, technology, or information systems, training, excessive tooling – excessive consumption of materials, which is usually caused by a bad correlation of assortment of purchased intermediates and technology processing needs (Wojciechowski, 2011; 5. Kuboń and Kurzawski, 2012).

Elimination of waste is often associated with introduction of modern production technologies and innovative product concepts, but usually it turns out that these concepts and technologies are proving to be extremely simple and ready to be implemented with an immediate effect (Womack and Jones, 2003; Malaga-Toboła et al., 2012).

Elimination of *muda* is associated with the achievement of high productivity, high quality of services and manufacturing, as well as an improvement of management organization. Organizations should be directed to accept a change and guide it and should be sensitive to and ready for changes (Harris, 2009).

The lean concept allows companies to act in an intelligent way, capably tailoring its activities to environment and surrounding where they occur. New ideas, information, or innovations implemented by organizations aim to improve organizational process and lead development of companies (Wójcik, 2009).

The most popular tools of Lean Manufacturing are: 5S, TPM, Kanban, Work Standardization, SMED (Golińska, 2012). The five pillars of the 5S method are the foundation to start the improvement of an organizational structure of a company (Feld, 2001). According to Takashi Osada, a company that is not able to introduce the 5S principles will not know how to perform other tasks that are required from another competitor (Osada, 1991).

In order to analyze organization of the studied production company two selected Lean Manufacturing tools were used:

- Standardization of work is designed to identify employees who strive for self-improvement. Therefore, owing to that detailed measurements of process, improvements can be made (Liker and Convis, 2012).
- SMED, the task of which is to reduce machine changeover time. The tool's name is an acronym for the English expression *Single Minute Exchange of Die*, meaning the exchange of mould within one-digit number of minutes. The use of this method leads to the planned necessary activities performed during changeover (Golińska, 2012).

Standardization of the selected worksites – research results

Development of the working standard is related to observation of operators' activities, examination of their repeatability, and then presentation of the results in a readable form.

The aim of the study was a detailed analysis of the production process of department 1 in a manufacturing company and on the basis of the obtained results beneficial changes were suggested.

The frequency of tasks performance by an operator also was recorded. Figure 1 observation sheet of an operator involved in preparation of raw materials in department 1.

In activities such as: to complement documents, no operator and awaiting time no task repetition is recorded. Tests carried out by an operator were being measured by a stopper during the study in order to calculate then average performance of each of them. Time measured at the time of operator's absence at the work position was marked with a purple color at a worksheet and with a red color the timeout of the operator working at the shift. The worksheet was created for each workposition in department 1.

Each worksite in department 1 was studied three times for the measurements to be most reliable. Every time worksite observation lasted eight hours that is duration of an operator's work in the studied company.

Based on the worksheet data, a list of activities, their frequency and time of their execution was created for each work position at department 1. The measurements were necessary to fill in the standardization work sheet.

The operators' standardization work sheet in department 1 allowed drawing attention to an unequal work burden of employees, which results from different levels of difficulty and a duration of each activity performed on workstations.

The overriding objective of this study was to propose changes that would help to increase the workload of operators from values below 50% to higher values to reduce disparities of operators in the department 1.

One of the changes included an additional activity for a production worker in charge of collecting and preparing materials. The additional task was to unpack defectively packed products. During production, defectively packed products can be reused in the production process. The products recovered from defective packaging waste are regarded as useful.

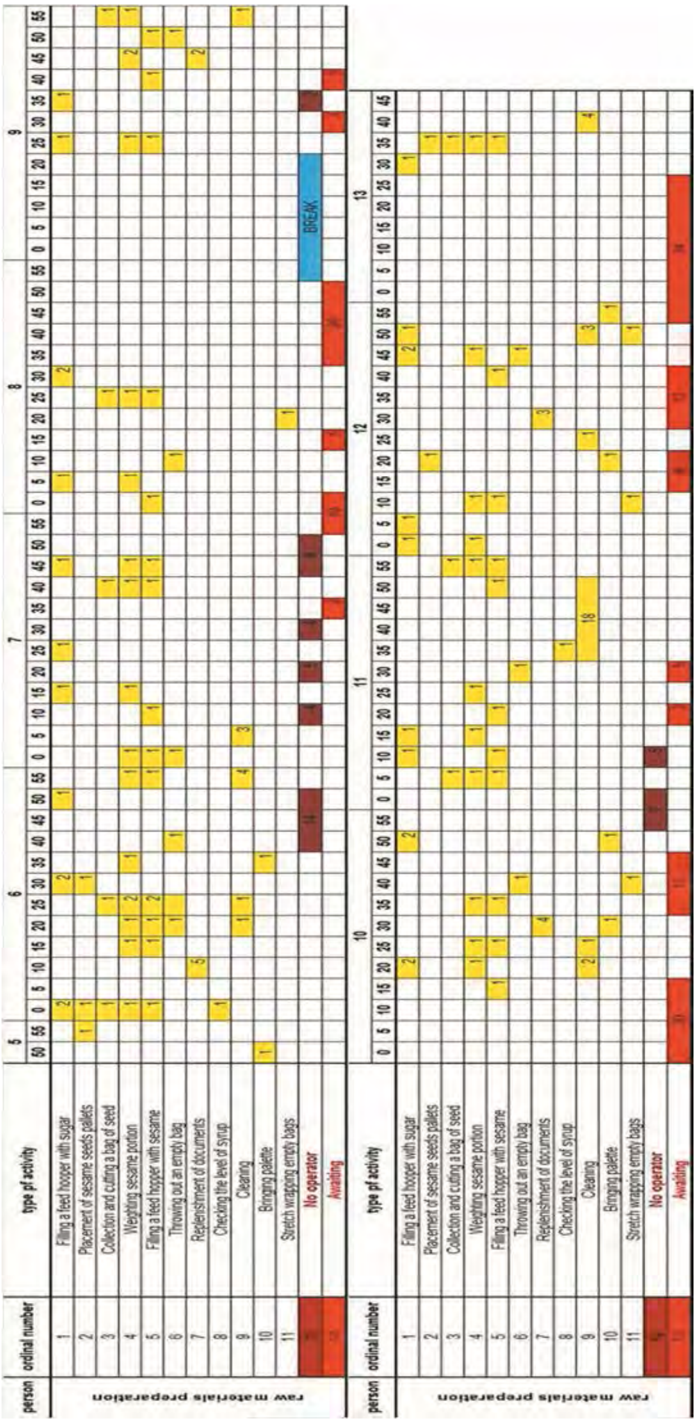
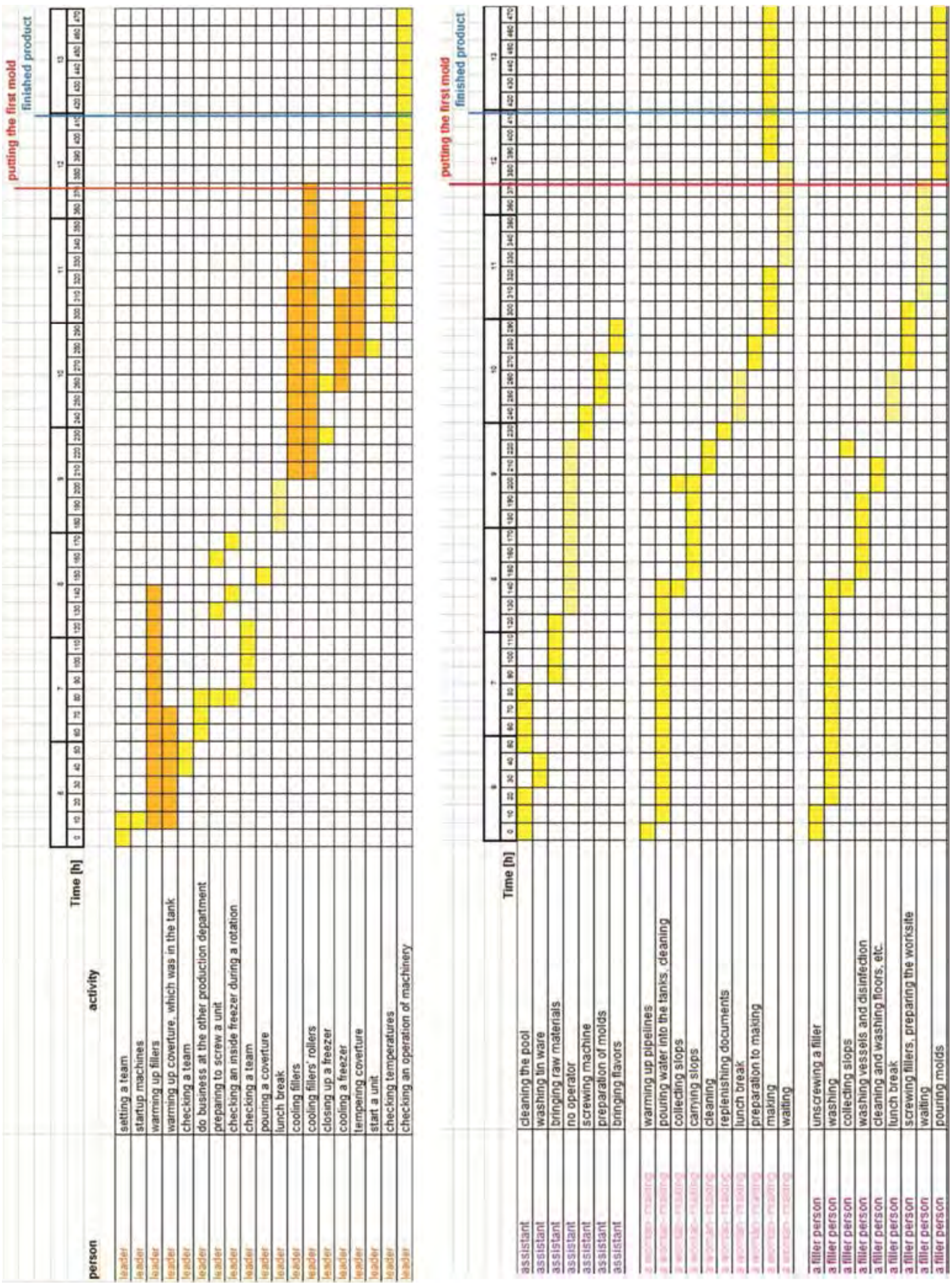


Figure 1. shows the activities carried out by an operator involved in preparation of raw materials in department 1. The third column lists various activities carried out by the operator at the position. Next columns show time change


putting the first mold
finished product
person
activity
Time [h]
setting a team
startup machines
warming up fillers
warming up coverture, which was in the tank
checking a team
do business at the other production department
preparing to screw a unit
checking an inside freezer during a rotation
checking a team
pouring a coverture
lunch break
cooling fillers
cooling fillers' rollers
closing up a freezer
cooling a freezer
tempering coverture
start a unit
checking temperatures
checking an operation of machinery
leader
assistant
cleaning the pool
washing tin ware
bringing raw materials
no operator
screwing machine
preparation of molds
bringing flavors
warming up pipelines
pouring water into the tanks, cleaning
collecting slops
carrying slops
cleaning
replenishing documents
lunch break
preparation to making
making
waiting
a filler person
unscrewing a filler
washing
collecting slops
washing vessels and disinfection
cleaning and washing floors, etc.
lunch break
screwing fillers, preparing the worksite
waiting
pouring molds

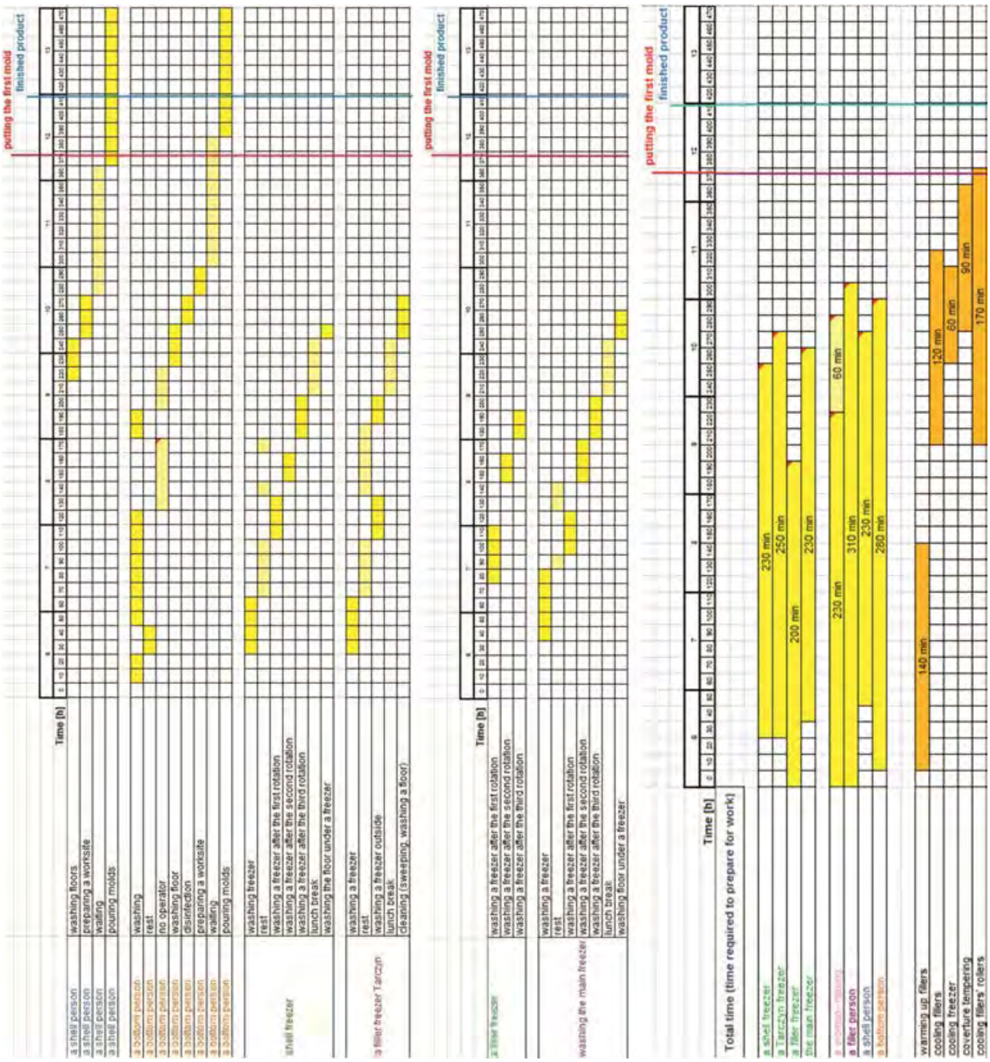


Figure 2. Presentation of the activities carried out by operators during the changeover

A study carried out in a department 1 allowed the increase of the efficiency of employees also in other work positions, among others, in case of an operator who is in charge of boiling the mass of a product 1 and in case of a worker involved in the formation of this mass. The workload of positions increased respectively: by 25% in case of an employee responsible for the production and preparation of raw materials collection, 14% for the boiling mass operator of product 1 and 15% in case of an employee engaged in the formation of this mass.

Furthermore, application of changes allowed reduction of a number of employees in the department 1 by one person. All tasks of a production employee responsible for pouring the cooked mass on the refrigerant table has been allocated to other operators, which made it possible to increase the workload of their work positions.

Reduction of the duration of tasks' performance in the selected processes – research results

Any process that involves an exchange of tools or equipment, switching a device or an employee team, not adding value is called a changeover. The SMED analysis aims to reduce the changeover time to less than 10 minutes. By reducing the changeover time, it is possible to increase production by employing the same operators of the production department, the same machines at the same time. Reduction of the time in which tasks are performed during a changeover increases the duration necessary to produce finished goods, thereby making possible reduction of the production batch size and amount of stocks, which is associated with reduction in the production costs.

In department 2 a problem with washing a unit for manufacture of product 2 was reported. The unit must be thoroughly cleaned once a week, and after each eight-hour break in service operators need to wash tanks for making fillings and fillings filler. This is a problem for the investigated company because it is very time consuming. Therefore, an investigation of the cleaning process unit by employees of department 2 was conducted. This analysis could fall into the SMED method, despite the fact that the name suggests one digit value of changeover duration.

The first step of the analysis was to investigate all activities performed by employees during the changeover. The measurements were carried out on several occasions so that the tests are to be the most reliable. Figure 2 shows example measurements carried out - activities carried out at each work position in the studied company, duration of individual tasks and awaiting time of individual operators, an insertion point of the first mold to the unit as well as the output of the first finished product. Time of transition of mold throughout the unit is about 45 minutes. The figure also shows a sheet of the total time needed for the preparation of a worksite.

Changes in the work organization of department 2's operators were proposed. The main objective was to start a unit in less than 300 minutes. The prepared plan of work organization change during the changeover has been accepted and quickly implemented by operators of department 2.

Conclusion

Introduction of standardization of department 1 transformed work into a process, which can be easily measured and improved. Standardization of work has given the company benefits such as: predictability of work owing to which it is known how much time is necessary to produce a finished product, stabilization and improvement of production process, increase of an operation frequency, increase of the process efficiency.

Owing to the work standardization sheet, changes to individual workstations could be made. Implementation of a new plan reduced workload's disparities of a department's staff. This change allowed elimination of waste in the form of non-productive time of operators. Moreover, it reduced the number of employees at the department 1 by one person, which improved the efficiency of the process.

The SMED analysis, performed at department 2, helped to shorten activities (performed by employees) during a changeover. Accurate observations and discussion on them had a positive effect on the change in the work organization in the company. Initial studies have shown a long awaiting time of operators. In addition, it was reported that the team had not exactly targeted the plan of action. Introduction of a new organization plan during the changeover allowed starting production with a significant advance.

Owing to the SMED analysis the studied company: increases uptime in terms of downtime associated with the changeover, reduces start-up time, reduces costs of changeover, eliminates performance of unnecessary activities.

Application of Lean Manufacturing tools helped eliminate waste reported during research. Waiting of operators at the worksites was primarily considered as waste.

During research the following methods were used to eliminate muda: observation of workers, which improves the quality of their operations and reduces non-productive work time, draw special attention to the causes of delays and losses, provide employees with valuable tips that help streamline the production process, a change of the company's culture from such where employees are interested in tasks to be done and they do them in an average way, into a company that focuses on a customer and enhances the value stream.

The so-called lean thinking is a perfect antidote to muda. Its task is to define the concept of value, ranking actions resulting in the formation of values in the most efficient way, carry out these activities without complications at times when they are necessary, as well as their more efficient implementation. In short, this is a "lean "approach because it shows how to produce more while consuming less and with less human labor, time, equipment and space, while retaining higher and higher degree of customer satisfaction (Productivity Press Development Team, 2003).

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WPŁYW WYKORZYSTANIA NARZĘDZI LEAN MANUFACTURING NA POPRAWĘ FUNKCJONOWANIA PRZEDSIĘBIORSTWA

Streszczenie. Celem artykułu jest ocena wpływu narzędzi Lean Manufacturing na organizację pracy dwóch wybranych działów przedsiębiorstwa produkcyjnego W celu określenia skuteczności koncepcji lean przedstawiono działania organizacyjne poprawiające wydajność procesu produkcji analizowanych działów. Do analizy wykorzystano standaryzację wybranych stanowisk pracy oraz skrócenie czasu wykonywania zadań w procesie produkcyjnym w czasie trwania przezbrojenia. Przeprowadzone badania pozwoliły potwierdzić hipotezę badawczą, że wykorzystanie narzędzi koncepcji Lean Manufacturing gwarantuje oszczędność czasu, zasobów, poprawia funkcjonowanie przedsiębiorstwa, eliminuje marnotrawstwo.

Słowa kluczowe: Lean Manufacturing, muda, SMED, standaryzacja pracy, organizacja pracy