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PROSPECTS FOR THE IMPLEMENTATION OF REAL ESTATE DEVELOPMENT IN UKRAINE BASED ON ENERGY EFFICIENCY PRINCIPLES AND THE PROBLEMS WITH RAISING THE FINANCE REQUIRED

Abstract
The main goal of the study is to analyse the residential real estate market in Ukraine from the point of view of the need and the possibility of increasing its energy efficiency. Also, it aims to justify effective financial and credit mechanisms for ensuring measures to improve the thermal protection properties of residential and non-residential real estate, in particular by introducing energy efficiency development projects. With this research we investigated Ukraine's housing stock and utility tariffs and concluded that a beneficial strategy to be applied in Ukraine is the energy-efficient retrofit of real estate. This is one of the most effective ways to re-profile unclaimed real estate units in the existing state or to reconstruct inefficiently used buildings. Also, we reviewed selected methods of energy efficient residential real estate development and mechanisms of financing energy-efficient renovation of real estate used in the EU. And, in our view, the next step of the Ukraine in the direction of improving the energy efficiency of housing should be the effective operation of a dedicated/specific energy efficiency fund to ensure stable financing of housing modernization projects, which will allow for a comprehensive renovation of buildings and lead to significant annual energy savings in this end-use sector.

Key words
thermo-modernization, housing stock, energy efficiency, financing mechanisms

Introduction

In the current economic conditions in the post-Soviet space of Ukraine, real estate development is becoming increasingly popular. We use this term to determine an activity for the implementation of investment projects in real estate for the creation or reconstruction or improvement of facilities with subsequent marketing, management, and disposal of results [4]. Often this is the reconstruction of irrationally used buildings. At the same time, modern world trends in the functioning of real estate requires determining the directions of reconstruction of the Ukrainian housing stock on the basis of increasing its energy efficiency.

Energy savings in the housing construction and housing and communal services end-use sectors can become a priority in our state. 61% of Ukraine's housing stock was built before 1970 of which 46% dates from post-war years and the first period of the introduction of industrial prefabricated apartment blocks (50-60 years), and the remaining 15% from the pre-war period. All of them require major repairs. More than 70% of the housing stock (about 105 million m2) requires thermo-modernization and a reduction of the energy consumption level, which now is about 210-240 kWh / m2 per year (on average for the housing stock as a whole), according to the estimates of the Ministry for Regional Development, Building and Housing of Ukraine [1]. Problems of shortage and a high cost of energy carriers, as well as low incomes of the population, do not allow the majority to pay utility bills, also provoke a decrease in energy consumption in the residential sector. Finally, the challenges of sustainable development, combating climate change requires urgent action on energy efficiency. Solving these issues is possible through the introduction of new energy-saving materials and technologies in the construction of new or reconstruction of obsolete buildings. Therefore, in the current conditions of rising energy costs, it is advisable to implement the development and redevelopment of the residential real estate only on the basis of energy efficiency.

Analysis of previous work by V. Barannik [2], S. F. Yermilov, V. M. Heiets, Yu. P. Yashchenko [3], R. B. Peiser, A. B. Frej [4], M. Dyba, Ye. A. Polishchuk [5] and also our own studies [6 – 10] have allowed us to identify the problems of the non-energy efficient functioning of a residential real estate in Ukraine and to suggest ways of their solution with the help of energy efficient development.

At the same time, little attention has been paid to research on mechanisms for financing development projects for the construction and reconstruction of housing on the basis of energy efficiency and energy conservation

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and justification of financing schemes [11]. In connection to this, a second aim of the study is to analyse the residential real estate market from the point of view of the need and the possibility of increasing its energy efficiency and the rationale through effective financial and credit mechanisms for ensuring measures to improve the thermal protection properties of residential and non-residential real estate, in particular by introducing energy efficiency development projects.

An analysis of Ukraine's housing stock

At the beginning of 2016, the residential housing stock of Ukraine increased by 1% compared to 2015 and amounted to a total 973.8 million m2 of built surface. The share of the residential housing stock in urban settlements represented the 60.8% (592.5 million m2) of the total. According to the State Statistics Service, 98.2% of entire housing stock was placed in the houses of apartment type, and 1.8% – in dormitories and residential premises in non-residential buildings [13].

The distribution of the housing stock by the years of construction (Fig. 1) shows that about half of the housing stock was put into operation in the post-war years and in the first period of the introduction of prefabricated apartment buildings (in the 1945 to 1970 period). A significant part of the country's housing stock, where about 50% of the population lives, is in an obsolete or in an emergency condition and requires major repairs. According to experts from the Ministry of Regional Development, as of January 1, 2017, about 90% of the housing stock would require thermal modernization [12, 13]. In this regard, more than 40,000 multi-storey buildings need to increase their energy efficiency and reduce the level of energy consumption through reconstruction and thermal upgrading.

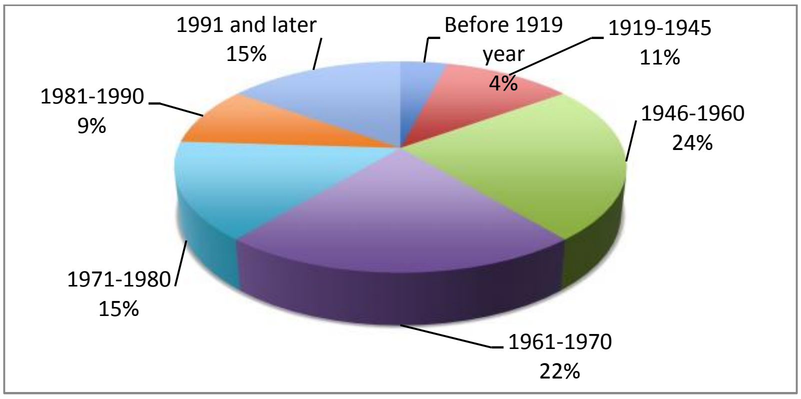

Fig. 1. Structure of the housing stock of Ukraine by years of construction

Source: [13]

For example, an inventory of the housing stock in the Poltava region – typical central region of Ukraine – found that the largest share (25.67%) the residential houses were put into operation in 1946-1960. And 22.94% of houses constructed in 1961-1970 (Table 1). At the beginning of 2016 out of 36 million m2 total area of housing in the Poltava region in poor condition were 170 thousand m2 premises [13].

Table 1. Distribution of residential houses by the year of construction in the Poltava region, number

	All houses	Including built in the period						
		Before 1919 year	**1919-1945**	**1946-1960**	**1961-1970**	**1971-1980**	**1981-1990**	**1991-2006**
Poltava region	423312	17751	52408	108668	97112	66801	50216	30356
Poltava (city)	21250	2326	1982	3082	3828	3432	3156	3444
Gorishny Plavny	2354	71	226	628	490	419	275	245
Kremenchug	16100	494	1784	3828	3564	2807	1878	1745
Lubny	9168	466	854	2093	2155	1882	1132	586
Mirhorod	7680	206	513	1610	1931	1861	1030	529

Source: [6, 13]

According to experts, Ukraine would need to prioritize the thermal modernization of houses constructed in the period 1971-1980 – which is about 105.1 million m2. In a second stage, buildings from the period 1981-1990 should be modernized. This situation is similar in most regions of Ukraine [12].

Fig. 2 shows the distribution of residential and non-residential buildings of the Poltava city by year of construction. Reconstruction and thermo-modernization are primarily needed for buildings located both in the central part of the city and in other areas.

Fig. 2 shows the distribution of residential and non-residential buildings in the city of Poltava according to the year of construction. Reconstruction and thermos-modernization is needed for buildings located both in the central part of the city, and in the more remote areas.

Fig.2. Territorial location of buildings and structures by the years of construction in the city of Poltava
Source: according to the information of City-Lab

The acute crisis of the entire economic system of Ukraine in 2014-2016 coinciding with the military intervention of Russia in Ukraine led to a reduction in the size of the construction industry at a rate faster than most other sectors (Fig. 3). That is, the construction of housing under the new energy efficiency standards is now practically impossible as the cost of such housing is too high, which makes it impossible to satisfy the needs of Ukrainians in high-quality, economical housing.

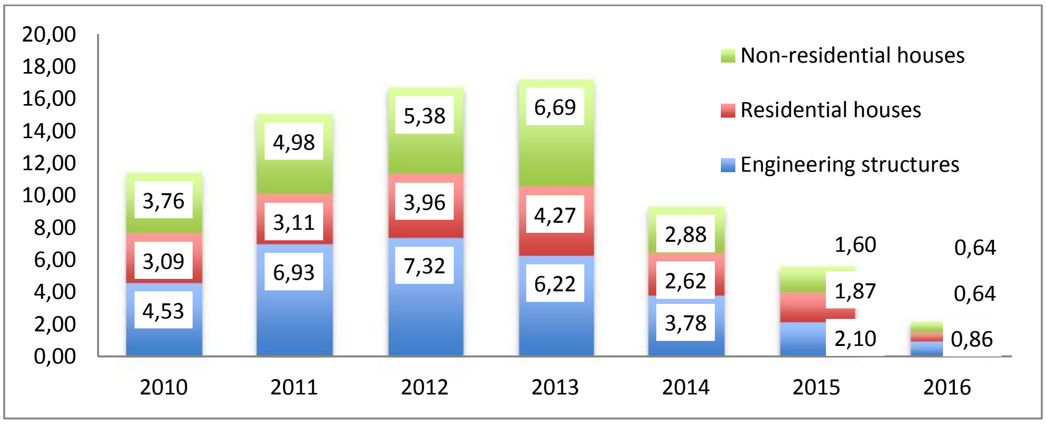

Fig. 3. Dynamics of the volume of completed construction work in 2010-2016, billion US dollars
Source: [14]

At the same time, a huge problem for the population of Ukraine is the constant increase in tariffs for utilities. Over the past 2.5 years the tariffs for district heating all over Ukraine grew up 5.5-10 times and for hot water 4.8 times (Fig. 4), while average wages increased by only 110% in 2008-2015, and by 37% in 2016-2017 – [15]. Limiting the household's energy consumption in this situation can only be considered as a temporary approach on the way to solving the energy saving problem.

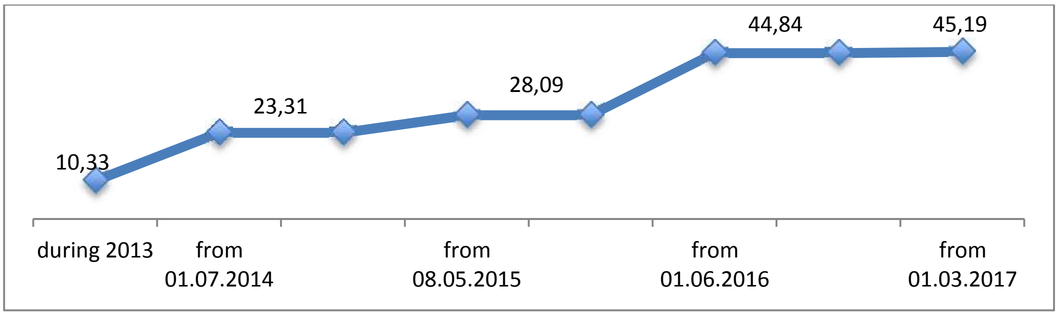

Fig. 4. Dynamics of the tariffs for "Kyivenergo" for heating with the use of meters, EUR/Gcal
Source: [16]

Since July 1, 2016, tariffs for heating and hot water for households have more than doubled. The average heat tariff for households in 2015 was 534 UAH/Gcal (21.4 EUR/Gcal), the weighted average tariff (according to The Ministry for Regional Development, Building, and Housing of Ukraine calculations), is set at 1303.36 UAH/Gcal (47.4 EUR/Gcal) from July 1, 2016 (Fig. 5) [1]. This is due to the establishment of a single gas price for households and businesses for heat and power utilities from 2.9 to 6.9 thousand UAH per thousand cubic meters.

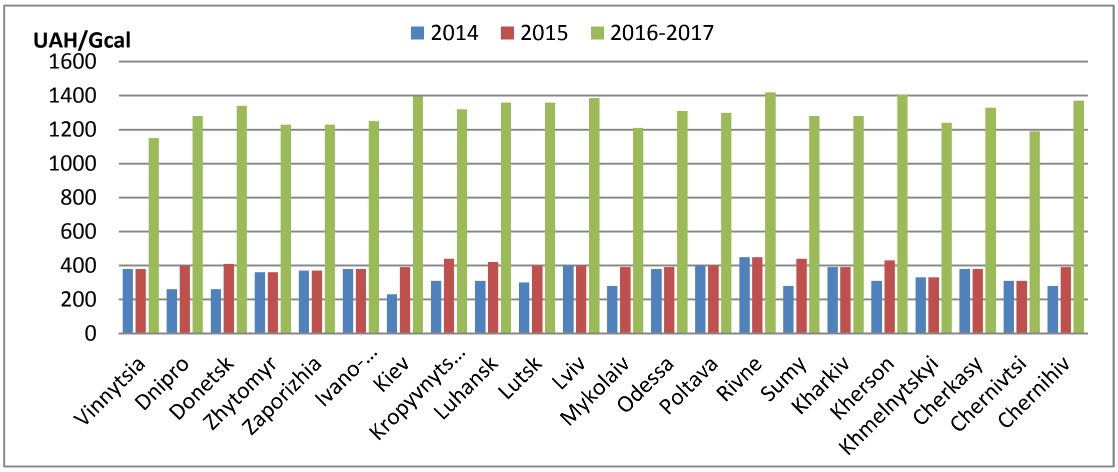

Fig. 5. Dynamics of tariffs for residents of apartment houses with house and apartment heat meters
Source: [13, 16]

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The level of domestic energy consumption for heating in Ukraine remains at the level of the building technical standards of the 80s (an average of 210-240 kWh / sqm per year). This figure is much higher than the European countries (about 125 kWh / sqm per year) [35].

Developed countries of the world and, first of all, the EU countries, have already achieved success to some extent in solving the problems of energy efficiency of buildings, ensuring the reduction of housing energy needs in heat and electric energy, continue to search for new sources of energy supply and development of energy saving measures. For example, by 2021, European countries plan to completely switch to nearly zero-energy buildings (NZEBs) and positive energy buildings that generate more energy than what they consume [18, 29, 30]. Such houses produce enough renewable energy to meet its own annual energy consumption requirements. The house is heated usually using alternative renewable energy sources (solar collectors, heat pumps, wind generators, etc.), and also taking into account the heat released by people who live in it, by household appliances, etc. At the same time, heat losses are prevented due to the design features of the building, for the construction of which modern energy-saving technologies and highly effective thermal insulation materials are used (Table 2).

Table 2. Consumption of thermal energy depending on the type of buildings the example of Germany

House area 140 m	**Annual energy consumption, kWh /(m^2a)**	**Specific heat loss, Wh /(m2)**
Old building	300	136
Typical house of the 1970's.	200	91
Typical house of the 1980's.	150	68
Low energy consumption house of the 1990's.	70	14-32
House of ultra-low power consumption	15-30	7-14
Modern Passive House	Less than 15	Less than 7

Source: [19]

Simplified energy-efficient home technology includes four main aspects: the thermal insulation of walls and roofing, the sealing of windows and doors, energy-efficient ventilation and the substitution of inefficient boilers. In general, these interventions allow reducing heat consumption and improving the financial value of housing. Also, measures for power management, automatic control, hydraulic balancing of the heating system, and thermostatic valves on the radiators contribute to energy efficiency. Reducing energy consumption also reduces environmental pollution from non-renewable sources of energy (natural gas, fuel oil, coal), which creates a positive effect on the environment both locally and globally.

The investment costs for a newly built energy efficient house are 10-20% higher than traditional one, mainly due to the costs of additional insulation and ventilation, but operating costs are 60-70% lower [20]. Given the Ukrainian energy costs, a 140 m2 home heated with natural gas, the potential annual savings of implementing these measures will amount to USD 1800, and to USD 1500 in the case of houses with electric heating [21].

According to the standards of state building codes of Ukraine V.2.6.-31: 2006 "Building. Structures for buildings and constructions. Thermal insulation of buildings" by 2014 [17] government already created an energy classification of buildings and developed the formula calculation of unit costs, but regulatory requirements are focused primarily on limiting consumption of heat for heating of buildings and require bringing to the European standards of comfortable living and the construction of passive houses.

Currently, the construction industry also created a legal and methodological framework for energy efficiency in the design and construction of housing for civil purposes, which provides energy savings of over 30% in buildings, compared to the corresponding rules in force until 1994 [21 – 23]. However, these regulatory requirements are mandatory only in the design and construction of new residential and public buildings and structures [31]. This constrains the reconstruction of existing facilities according to the European energy efficiency requirements. However, in the EU energy efficiency reconstruction is generally accepted and is supported in every way at the state and local levels.

In nowadays Ukraine where district heat tariffs grow and there are increasing problems with the operation of obsolete buildings, an urgent retrofitting of the country's old housing stock is required. One of the best ways that can be used in Ukraine is an energy-efficient development or redevelopment of real estate. This is one of the most effective ways to re-profile (reassign) unclaimed real estate units in the existing state or to reconstruct inefficiently used buildings. It benefits not only the developers but also the city, as it provides for the modernization of real estate, the improvement of the urban environment, the quality of life.

The financing and implementation of real estate development in Ukraine

Table 3 presents the proposed method of energy-efficient residential real estate development in Ukraine.

Table 3. Methods of energy efficient residential real estate development used in the world practice

Principles	Methods
Methods based on the principle of autonomy	Use of renewable energy sources (solar collectors, solar panels, heat pumps)
	Use of rainwater, recycling water
	Light sensors
	Efficient window constructions
	Green roof
	Thermal zoning of houses and apartments
Methods based on the principle of architectural efficiency	Bulk shape selection
	Reducing the ruggedness of external walls
	Increase the width of the section body
	Creating houses of the corridor type
	Compact house
	Maximum directionality to the south
Methods based on the principle of environmental friendliness	Greening facades
	Greening of roofs
	Landscaping of local areas
	Reducing traditional energy sources
Methods based on the principle of socio-economic expediency	Increase in the number of apartments per staircase-elevator unit
	Compliance with the requirements for the area of apartments
	Application of different types of sections
	Application of different types of apartments

Source: [11]

The approval of the law on the complex reconstruction of quarters (micro-districts) through an obsolete housing fund should also contribute to positive moves in the direction of the retrofitting of the housing stock.

Energy-saving development projects require significant capital investment. Energy efficiency projects can be financed using different mechanisms and sources of financing. The economic mechanism for introducing energy-saving technologies in construction and retrofitting of housing should include tax exemptions for investors, accelerated depreciation of energy-saving equipment, financial support for leasing energy-efficient equipment, soft loans.

The current legislation provides the following sources of capital for financing energy-efficient renovation of real estate:

- Financial resources of investors participating in the implementation of reconstruction projects, replacement of housing stock;
- Financial resources from reconstruction funds, replacement of housing stock;
- Financial resources in the form of regional, district, district budgets in cities and local government budgets [22, 25].

However, in the context of the post-2014 economic crisis and the lack of budgetary resources for capital expenditures and for maintaining programs at both the state and local levels, as well as problems in the banking sector, the funds of international financial organizations and private investors can serve as alternative or complementary sources of financing for residential real estate retrofitting projects.

The main international financial institutions, organizations and funds that finance and finance energy saving projects in Ukraine include: the World Bank (WB), the European Bank for Reconstruction and Development (EBRD), the International Finance Corporation (IFC), the Nordic Environment Finance Corporation (NEFCO), The Eastern Europe Energy Efficiency and Environment Partnership (E5P), the United States Agency for International Development (USAID), the German Society for International Cooperation (GIZ), The Swedish International Development and Cooperation Agency (SIDA).

Table 4. The programmes of international donor organizations to support energy-efficient projects in real estate in Ukraine

Donor	Name	Features
The International Finance Corporation (IFC)	"Energy efficiency in the residential sector of Ukraine"	Formation of the regulatory framework, which would allow homeowner associations (HOAs) and apartment buildings management companies to receive funding to improve the energy efficiency of apartment buildings. Cooperation with Ukrainian banks in developing and promoting market viable loan products designed for HOAs and apartment buildings management companies.
The German Society for International Cooperation (GIZ)	"Energy Efficiency in Buildings"	The project provided assistance to four Ukrainian cities on energy audit, business planning and energy monitoring system and training. The project supported the development of business plans for the NEFCO Energy Savings Programme in Chernihiv, Ivano-Frankivsk, Mirgorod and Novohrad-Volynsky.
	"Energy-efficient buildings"	On the basis of a new complex of residential and office buildings in Kyiv, energy-saving construction concepts are being implemented using modern, environmentally friendly technologies. The results of this pilot project are distributed through the Ukrainian construction sector.
	"Energy Efficiency in Communities"	Supporting the ability of local self-government to play the leading role in Ukraine in implementing energy-efficiency measures. Including facilitating access to funds and credit lines for financing such activities. Within the framework of the GIZ project and the Ministry of Regional Development, five consortia of cities were selected for participation. The leader of the consortium of cities is the Poltava Regional State Administration.
The German Development Bank (KfW)	Cooperation with ProCredit Bank	Financial and technical assistance to ProCredit Bank in providing loans to small, medium and large businesses and households to improve energy efficiency. The credit line is 35 million euros, with a maturity of 7 years.

Source: [26, 27]

However, the funds allocated for these pilot programs are not enough to address the energy inefficiency of Ukraine's housing stock. In connection to this, there is an urgent need to search for new models and schemes for financing projects for the reconstruction and improvement of buildings' energy efficiency, including the implementation the world practice of using tools applied in other countries.

One of these alternatives financing mechanisms are revolving funds, i.e., a fund set up for specified purposes with the provision that repayments will be used again for the purposes of the fund [28]. Continual reinvestment in projects with little payback period accumulates new resources at the expense of cash flows that come into the fund. The revolving fund model is an effective financial mechanism in cases of budgetary shortages in local and regional administrations. Because the energy efficiency revolving funds usually offer loans on more loyal terms than banks. The repayment of such loans is achieved through energy savings and the returned loans are used to finance new energy efficiency projects. In fact, the revolving fund – a special bank account, opened by a non-governmental organization (NGO). Also, the transactions of such an organization are not taxed.

A proposal of indicative financial conditions for a revolving fund can be:

- Loans from 15.000 to 500,000 euros, which can be given to private single-family house owners, groups of the owners of individual apartments, who cooperate with each other on the basis of a certain

contract, or homeowner associations/HOAs (provided that the legislation will have clear mechanisms for paying the HOAs o its obligations);
- The borrower's contribution to investment is at least 10% of total amount;
- A grace period of 2 years with a 10-year return period;
- A grant of 20-35% of total investment costs of housing retrofit is issued;
- 10% annual interest rate that may be subject to discussion in accordance with the risk assessment of a particular project;
- Management fee (3%);
- The cost of technical assistance [11].

Another type of models used in other countries that could potentially be tested in Ukraine is the ESCO model. Energy Performance Contracting (EPC) is a kind of project-financing mechanism involving third-party investments, where the main goal of the implementation is to increase energy efficiency or reduce energy consumption. Usually, the executors of EPC projects are professional energy service companies (ESCOs) [7].

The ESCO model is one of the solutions that have proved its effectiveness in working with consumers (in many European markets). However, it should be noted that ESCOs are mainly used in public sector projects, whereas this model is not very common private housing in Europe. In some countries, such as Sweden, Estonia, and Lithuania, ESCO models have been commercially successful in the residential sector (according to the ECEEE Report “Latest developments of the ESCO industry across Europe”, 2017) [33]. The ESCO is usually considered a good model for implementing energy efficiency projects.

ESCO models were introduced for the financing of energy efficiency in Ukraine at the beginning of 2000. However, this business is developing more in the industrial sector or in the sphere of small and medium-sized enterprises, while the demand for these services hasn't appeared yet in the residential sector [11]. Also since 2016, ESCOs have been implementing projects to improve the energy efficiency of public buildings. In 2016, 27 tenders were announced, and after successful completion of tender procedures, another 38 ESCOs were signed for the amount of more than UAH 40 million. In 2018 it is expected to conclude more than 250 energy service agreements [32].

Finally, a classic instrument for financing projects for the reconstruction and improvement of energy efficiency of housing are special preferential loan programs offered by banks with the support of the government or local authorities. A striking example of the support and encouragement of the population to the reconstruction of the housing stock in Germany is a special credit program of the German Development Bank (KfW), 80% of which belongs to the federal government and 20% to the federal lander. The bank offers 3 credit programs: “Energy-Efficient. Building. Refurbishment (151/152)” amounting to 100,000 € for a period of up to 30 years at 1.62% per annum with a grace period of one year return; “Renewable energy sources (167)” amounting to 50,000€, for a period of 2 to 20 years at 1.05% per annum and “Energy efficient repair (additional credit)” conditions, are individually discussed [27, 33].

Summary and conclusions

The current state of the housing stock in Ukraine requires the early resolution of the problem of increasing energy efficiency in the residential sector, as well as the energy and economic situation in the country. In general, the experience of developed countries indicates the need for state regulation of energy saving processes in the field of real estate and conduct a well-defined policy, as they are on the one hand strategically important, but on the other require significant financial resources available. Only the state can ensure the efficiency of financial mechanisms to improve the energy efficiency of real estate operation through a balanced legislation, flexible price, financial, tariff and tax policies.

Recent years have seen growing attention by state, owners, and developers to the energy efficiency of buildings, and, accordingly, the use of modern technologies to significantly reduce energy consumption in the residential sector, as well as improve living conditions and reduce the residents' funds to pay for housing and communal services. In view of rapidly rising in energy prices (in particular, natural gas), the important measures should be taken by the state to stimulate energy saving in the housing stock and introduce mechanisms for the financial provision of such measures.

Simple and effective lending models for energy efficiency measures that are applicable in world practice can prove their effectiveness in Ukraine. Given the current financial and economic situation and the existing legislation, it is necessary to develop first of all a bank lending model for thermo-modernization and a model of a revolving fund for energy efficiency. The model of ESCO financing is still rather difficult to use in housing stock of Ukraine.

Bank lending is to be financed by credit programs from European banks (for example, from the EBRD), as well as loans guaranteed by the government of Ukraine. This will allow granting subsidies for the capital reconstruction of the housing stock, but it requires considerable state subsidiarity support.

Another potentially attractive and efficient model is the creation in Ukraine of a revolving fund for energy efficiency. Typically, such funds provide soft loans. The fund can be created with the participation of European banks, the government of Ukraine, the National Bank of Ukraine, other donors. This model quite simply and effectively allows consolidating the funds of the state and other donor organizations interested in supporting energy efficiency in the housing sector. With the help of such funds, reinvestment in new energy-saving projects takes place, which increases the efficiency in the use of public funds. At the same time, this encourages local banks to enter the market for investments in energy efficiency in the residential sector. However, due care must be taken to ensure that such a fund enables effective control over the distribution and expenditure of funds, and generally operates in a transparent, public manner.

References

[1] The Ministry for Regional Development, Building and Housing of Ukraine, official website, http://www.minregion.gov.ua.

[2] V. Barannik, Energy efficiency in the state as an indicator of competitiveness. Interstate comparison, Economic bulletin of NTUU „KPI" (2010), http://economy.kpi.ua/files/files/3_kpi_2010_7.pdf.

[3] S. F. Yermilov, V. M. Heiets, Yu. P. Yashchenko, Energy Efficiency as a Resource of Innovative Development: National Report on the Status and Perspectives of Implementing the State Energy Efficiency Policy in 2008, NAER, Kyiv, 2009.

[4] R. B. Peiser, A. B. Frej, Professional Real Estate Development: The ULI Guide to the Business Second Edition, ULI-the Urban Land Institute, Washington, D.C., 2003.

[5] M. Dyba, Ye.A. Polishchuk, Developerski kompanii na investytsi-inomu rynku Ukrainy, KNEU, Kiyiv, 2011.

[6] T. Zavora, Energy efficiency of housing in the context of ensuring the energy security of the state, Economic aspects of energy conservation: problems and ways of their solution: collective monograph, V. Chevganova (Eds.), PoltNTU, Poltava, 2015, pp. 145 – 151.

[7] L. Svistun, Prospects for the development of ESCO financing of energy efficiency projects in Ukraine, Problems of Formation and Development of Innovative Infrastructure: European Vector - New Challenges and Opportunities, Abstracts at the III International Scientific and Practical Conference, Lviv Polytechnic, Lviv, 2015, pp. 302-303.

[8] L. Svystun, Y. Khudolii, T. Zavora, Directions of energy efficiency in the construction sector in view of the foreign experience, Energy efficiency of the economy: problems of today and tomorrow: International scientific-practical conference, PoltNTU, Poltava, 12 – 13 October 2016, pp. 66 – 71.

[9] Y. Khudolii, T. Zavora, L. Svistun, Preconditions for the introduction of thermo-modernization measures of the housing fund in Ukraine, Abstracts at the 15th International Scientific Conference Information Technologies and Management 2017, Riga, Latvia, 27 – 28 April, 2017, pp. 138 – 139.

[10] T. Zavora, L. Svystun Y. Khudolii, Conceptual bases of formation of a housing policy based on energy efficiency and energy conservation, Energy efficiency of the economy: problems of the present and future: collective monograph, PoltNTU, Poltava, 2017. pp. 46 – 62.

[11] Thermo modernization of housing stock: organizational, legal, social, financial and technical aspects: practical issue, third ed., V. Bryhilevych (Eds.), Lviv, 2016, http://www.cdms.org.ua/Files/TermModH.pdf.

[12] In Ukraine, about 90% of high-rise buildings require thermo modernisation (2016), http://www.nova.poltava.ua/v-ukraïni-blizko-90-bagatopoverxivok-potrebuyut-termomodernizacii/.

[13] Residential fund of Ukraine, http://ukrstat.org/uk/operativ/menu/menu_u/if.htm.

[14] Development of the construction industry 2010-2016, Ukrainian Center of Steel Construction (2016).

[15] The purchasing power of the Ukrainian is falling more and more, http://publicaudit.com.ua/news/kupivelna-spromozhnist-ukrayintsiv-vse-bilshe-padaye.

[16] Changes in tariffs for heat energy for households, National energy and utilities regulatory commission, official website, http://www.nerc.gov.ua/data/filearch/teplo/dynamika_taryfy/naselennia/Dynam_taryfy_teplo_naselennia.pdf

[17] State building codes of Ukraine V.2.6.-31: 2006 "Building. Structures for buildings and constructions. Thermal insulation of buildings", http://dbn.at.ua/load/normativy/dbn/1-1-0-13.

[18] A Common Definition for Zero Energy Buildings" (2015), US Department of Energy, https://www.energy.gov/sites/prod/files/2015/09/f26/A%20Common%20Definition%20for%20Zero%20Energy%20Buildings.pdf.

[19] Energy Efficiency Standards in Europe and Germany, ESCO. Energy service, Volume 8, 2013, http://www.journal.esco.co.ua/esco/2013_8/art32.html.

[20] Passive house for the price of a two-bedroom apartment (2017), http://akvilonpro.ua/ru/docs/passive-house/Pasivniy-dom-po-tsene-trehkomnatnoy-kvartity.html.

[21] N.O. Kondratenko, I.S. Balandina, Aspects of the problem of rationing energy consumption in housing construction, Municipal economy of cities, Volume 87, 2009, pp. 70-76.

[22] About the Concept of State Housing Policy: Verkhovna Rada of Ukraine Resolution № 254/95-BP from 30.06.1995, Information from the Verkhovna Rada of Ukraine, Volume 7, 1995, pp. 200.

[23] Draft Law of Ukraine "On the energy efficiency of residential and public buildings", http://w1.c1.rada.gov.ua/pls/zweb2/webproc4_1?pf3511=53059.

[24] N. V. Mytsa, Essence and problems of energy saving in Ukraine, Sustainable development of economy, Volume 4, 2011, pp. 40-47.

[25] V. Onishchenko, T. Zavora, Organizational and economic aspects of modern housing policy: a regional dimension, Poltava, PoltNTU, 2011.

[26] L. Svistun, Y. Dovgal, Mortgage lending in Ukraine: current problems and development factors, PoltNTU, Poltava, 2014.

[27] Energieeffizient Sanieren – Kredit, https://www.kfw.de/inlandsfoerderung/Privatpersonen/Bestandsimmobilien/Finanzierungsangebote/Energieeffizient-Sanieren-Kredit-(151-152).

[28] „Revolving Fund” Merriam-Webster.com. (2018), https://www.merriam-webster.com/dictionary/revolving fund.

[29] Nearly zero-energy buildings, European Commission, https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings.

[30] EPBD Directive 2010/31/EU on the energy performance of buildings, http://www.rehva.eu/en/epbd.

[31] New energy strategy of Ukraine until 2020: security, energy efficiency, competition, http://old.razumkov.org.ua/upload/Draft%20Strategy_00%20(7).pdf.

[32] State Agency for Energy Efficiency and Energy Conservation of Ukraine, http://saee.gov.ua/uk/content/energoservis_1.

[33] Real Estate Financing. (2015). Wealth Opportunities in Commercial Real Estate, pp. 119–155, DOI: 10.1002/9781119202790.ch5.

[34] Latest developments of the ESCO industry across Europe (2017), https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2017/.

[35] Household energy consumption for space heating per m2 (2015), https://www.eea.europa.eu/data-and-maps/daviz/unit-consumption-of-space-heating#tab-chart_1.

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THE PHOTOLUMINESCENT LAYERS BASED ON ZnO NANOPARTICLES AS RADIATION CONVERTERS IN PHOTOVOLTAIC APPLICATIONS

Abstract
The mismatch between solar cell response and solar spectrum is one of the biggest challenges to achieve high efficiency in photovoltaic cells. There are a few different approaches to minimise this concern. One of them is the radiation conversion which may be due to three different processes, namely up-conversion, down-conversion and down-shifting. In this paper the down-conversion process of zinc oxide nanoparticles (ZnO NPs) and layers with ZnO NPs in polymer (poly (methyl methacrylate)) (PMMA) matrix will be analysed. ZnO NPs are prone to act as down-converting or down-shifting agents, which absorb the UV radiation, which is not absorbed by the solar cell, and then re-emit light in the visible range, which is suited to the photovoltaic cell sensitivity. Herein, the photoluminescence and optical transmittance of ZnO NPs and layers based on ZnO NPs will be presented. These parameters have a large influence on the potential application of these layers in photovoltaic structures for increased efficiency. The conversion layers have to fulfil the following conditions: have good optical transmittance in the visible range and high luminescence efficiency in converting UV radiation into visible. The paper focuses on finding the balance between these parameters.

Key words
down-conversion layers, down-shifting layers, photoluminescence nanoparticles, solar cell efficiency, zinc oxide nanoparticles, photoluminescence layers

Introduction
The photoluminescence effect has a wide spectrum of applications in many different domains of industry [1-3]. In photovoltaics it is used in the non-destructive quality control of solar cells [3, 4], the luminescent solar concentrator [5] and radiation converters [6, 7]. Fundamental spectral losses arising from the limited spectral response of solar cells to the solar radiation spectrum create the greatest part of the deficiency of photovoltaic devices. These losses limit the theoretical maximum efficiency of a single junction solar cell with an energy band-gap of E_g = 1.1 eV (c-Si cell) to a mere 31% [8]. During the last few decades various concepts have been proposed to overcome that limit such as multi-junction solar cells, interband transitions or radiation conversion methods [9-11].

The three fundamental radiation conversion processes: up-conversion (UC), down-conversion (DC) and down-shifting (DS) are schematically presented in Fig. 1. The first process permits the conversion of infrared light into visible light by the simultaneous absorption of two photons and emission of one photon with higher energy. In the down-conversion process one photon with higher energy can be converted into two photons of equal energy, two times less than the one absorbed. The last one (down-shifting process) is a variant of the down-conversion technique, which permits the conversion of a high-energy photon into lower-energy photons [6, 7, 10, 11].

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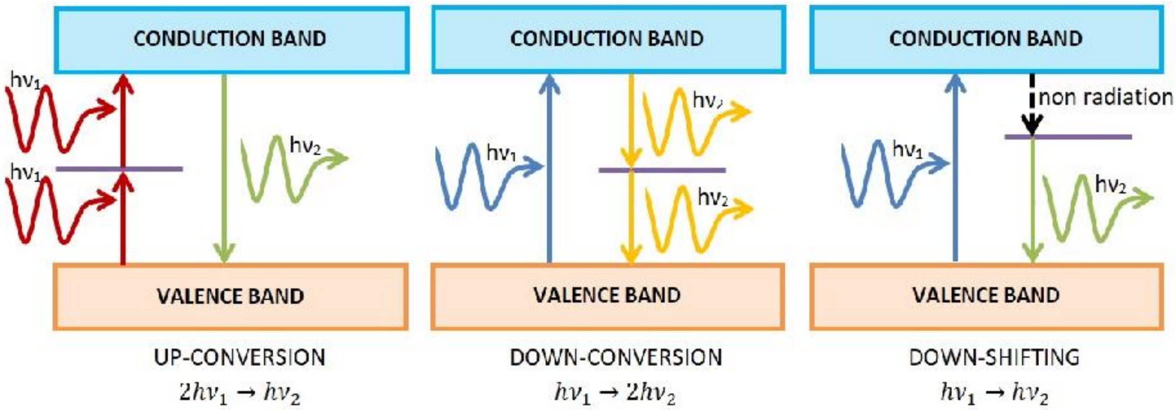

Fig. 1. Schematic of the converting processes: up-conversion, down-conversion and down-shifting.
Source: Authors

The use of down-conversion to improve solar cell efficiency was first investigated by Dexter [12]. More than 20 years later, Hovel et al. [9] proposed down-shifting, a similar process. During the last few decades various materials were examined for application of the down-conversion or down-shifting process [13, 14]. Abrams et al. [10] and Trupke et al. [11] calculated the increase of a conventional single-junction solar cell efficiency equal to 7% as a result of the application of a down-converting layer. A similar conclusion was reached by Gabr et al. [15]. The enhancement of solar cell efficiency with the application of down-converting layers incorporating rare earth (RE) elements [16-18], quantum dots [19-22] and others [6, 13, 14, 23] has been observed. For example the influence of conversion layers based on RE at solar cell efficiency was studied for dye-sensitized solar cell (DSSC) using ZnO doped various RE where the rise of efficiency is about 2% [17]. The similar rise was observed for the same type of solar cell using SrAl2O4 with Eu and Dy [18]. The application of CdS QDs as converters in GaAS solar cells causes the increase of efficiency for about 3% [22]. ZnO NPs was analysed in [6] where the growth of efficiency was observed for CIGS and CdTe solar cells for almost 1% absolutely what give the relatively rise for about 5%.

The results of a computer simulation of zinc oxide nanoparticles (ZnO NPs) using SCAPS (Solar Cell Capacitance Simulator) software suggested a possible increase of solar cell efficiency of about 2% to 3% for different photovoltaic structures: traditional polycrystalline silicon (poly-Si), cadmium telluride (CdTe) and copper indium gallium selenide (CIGS) solar cells. The higher influence of the layers was observed for CdTe solar cell [24]. The photoluminescence properties and optical transmittance change (due to the refraction coefficient change) have the main influence on that. In this paper the properties of manufactured down-converting layers based on ZnO NPs are analysed and discussed.

Zinc oxide (ZnO) is a direct bandgap semiconductor with great potential for a variety of applications. A wide bandgap of 3.37 eV achieved at room temperature [23] makes ZnO a promising material for optoelectronic and photonic applications in the UV or blue wavelength spectral range. At the same time, the high exciton binding energy ensures an efficient exciton emission even at room temperature. Furthermore, ZnO has many advantages. It is cheap, abundant and an environmentally friendly material which exhibits a visible emission related to crystal defects, suitable for down-shifting [23]. Also, its semiconducting properties make ZnO sensitive to the doping process. One of the most popular doped material is aluminium (Al) which creates an aluminium-doped zinc oxide (AZO). The AZO is a highly conductive n-type material. The doping of ZnO also influences its optical properties [25, 26] which can be used to tune the emission colours.

Materials and Methods

The down-conversion layer was deposited by spin-coating methods at various spin speeds of: 1000 rpm, 2000 rpm, 3000 rpm, 4000 rpm, 5000 rpm and 6000 rpm. The layer's matrix is a poly (methyl methacrylate) (PMMA) compound with an average molecular weight of 350000 by GPC, purchased from Sigma Aldrich Company. The material used to convert the UV radiation to visible range is ZnO NPs, purchased from IoLiTec Company (Ionic Liquids Technologies). The average ZnO NPs size is 20 nm. The solvent used was chlorobenzene.

The mixtures were prepared with different mass concentrations of ZnO NPs: 1%, 2% and 5%. Firstly, the ZnO NPs, PMMA and chlorobenzene were weighted. The mass concentration of the PMMA was 8% in the base matrix. Subsequently the mixtures were put in an ultrasonic cleaner for 30 minutes. In this way, the ZnO NPs are distributed in smaller agglomerates and are homogeneously distributed in the layer. Consequently, the samples were stirred with a magnetic stirrer for 24 hours under hermetic cover. Just before the deposition of the DC layer the mixtures were put into the ultrasonic cleaner for 30 minutes once again. In this case two kinds of substrates were used: quartz and silicon for optical transmittance measurements, photoluminescence measurements and scanning electron microscope (SEM).

The photoluminescence properties of the manufactured ZnO NPs layers were measured using an FLS980 (Edinburgh Instruments) fluorescence spectrometer with a 450 W excitation source ozone free Xenon Arc Lamp and R-928 photomultiplier detector. The optical transmittance was measured with a Filmetrics aRTie-UV LS-DT2. The SEM analysis was made with a Carl Zeiss EVO MA10 SEM scanning electron microscope using two detectors: SE for analysing secondary electron image and BSD for analysing backscattered electron image.

Results and Discussions

The optical properties of the DC layers were analysed. Considering the results of computer simulation [24], the optical transmittance should be as high as possible. When it is less than 85% the DC layer will not enhance the solar cell efficiency. This is caused by the fact that the layer absorbs the radiation, also from the visible range, which is used in photoconversion process in the solar cell. In Figs. 2-4 the characteristics of optical transmittance for the DC layer with different concentrations of ZnO NPs are presented. The line of 85% optical transmittance is marked in all figures. This level is exceeded for DC layers with ZnO NPs in concentrations of 1% and 2% for all spin speeds for wavelengths below 400 nm. Although the level of 85% optical transmittance for the DC layer with 5% ZnO NPs concentration is achieved with a spin speed of 1000 rpm at a wavelength of 540 nm. With a spin speed of 4000 rpm and more it is exceeded at a wavelength of 430 nm. High optical transmittance in the visible range is so important due to the effectiveness of utilisation of this radiation by solar cells. Moreover, the optical transmittance for 4000 rpm spin speed and higher is similar to each other for all concentrations of ZnO NPs.

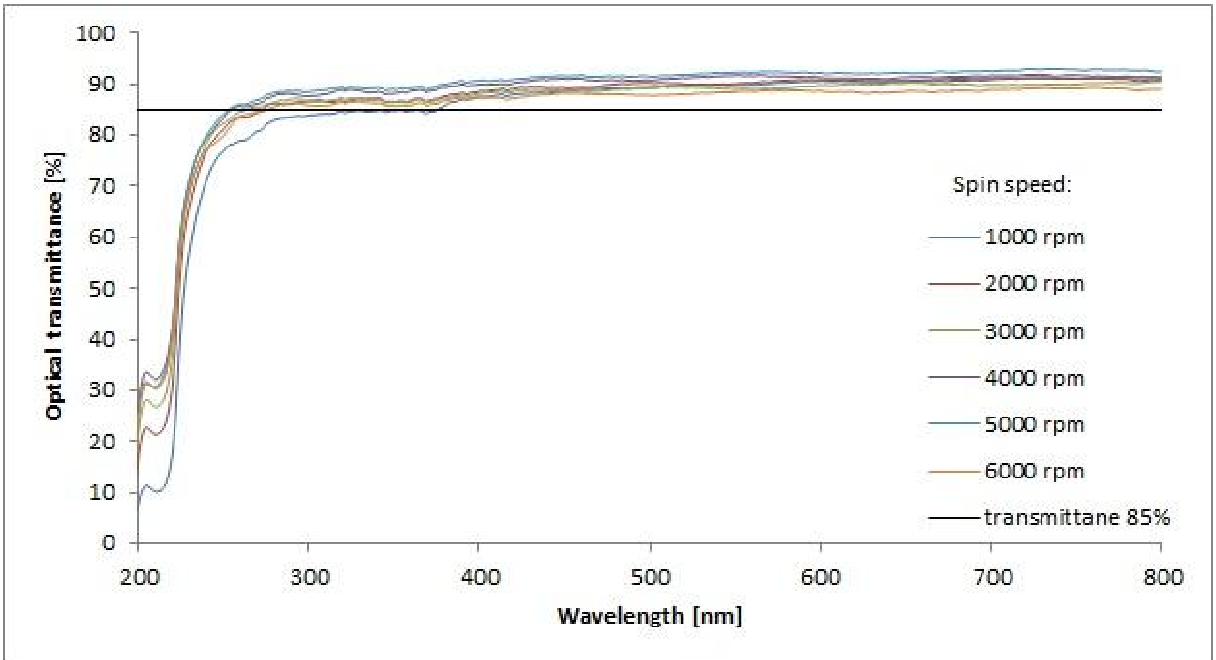

Fig. 2. Optical transmittance of down-conversion layer with ZnO NPs of 1% concentration.
Source: Authors

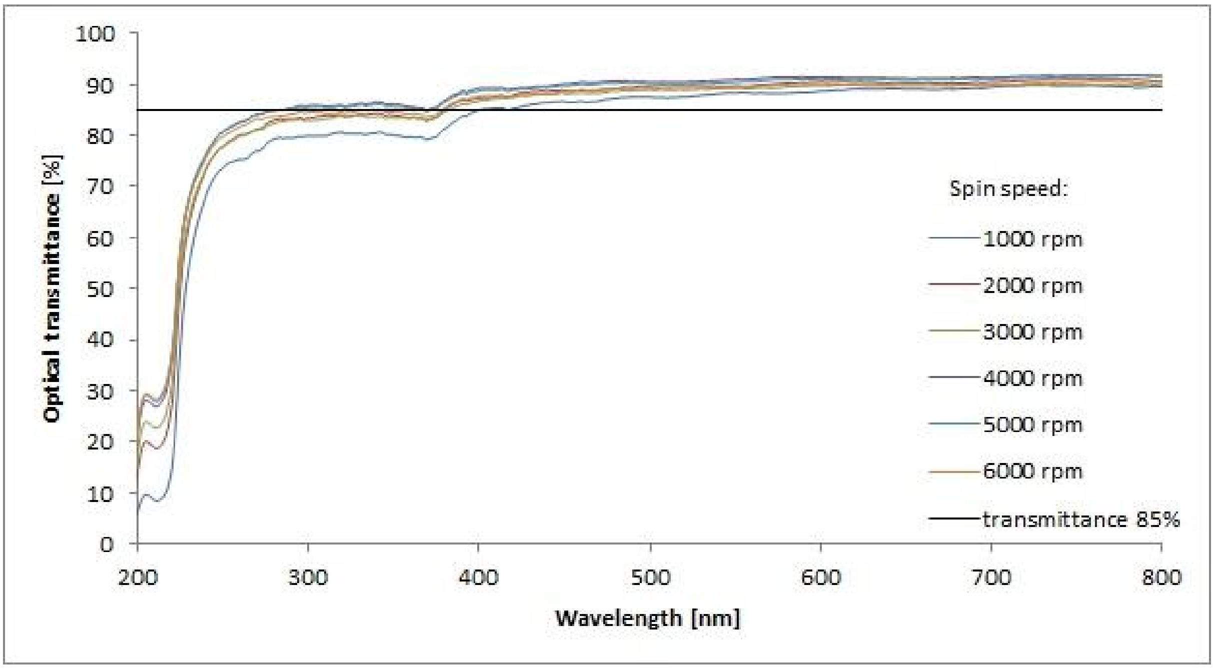

Fig. 3. Optical transmittance of down-conversion layer with ZnO NPs of 2% concentration.
Source: Authors

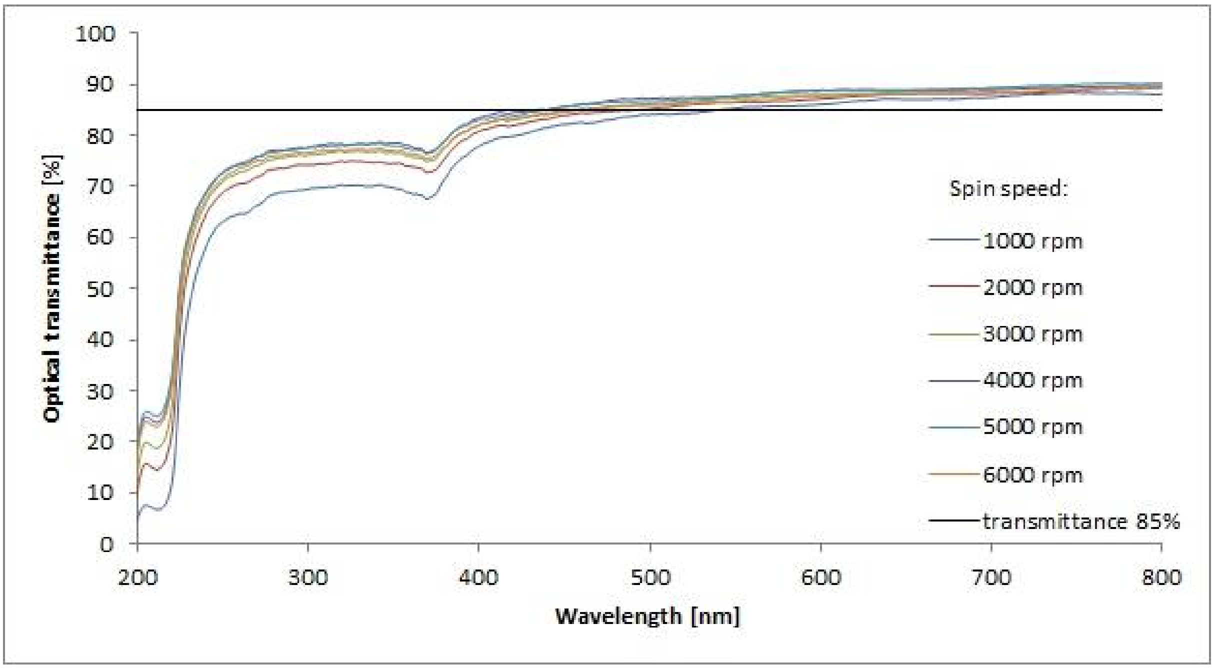

Fig. 4. Optical transmittance of down-conversion layer with ZnO NPs of 5% concentration.
Source: Authors

Fig. 5 presents the emission spectrum of zinc oxide nanoparticles in powder for various excitation wavelengths. The results show that examined ZnO nanoparticles have desirable photoluminescence properties to convert UV radiation into visible light.

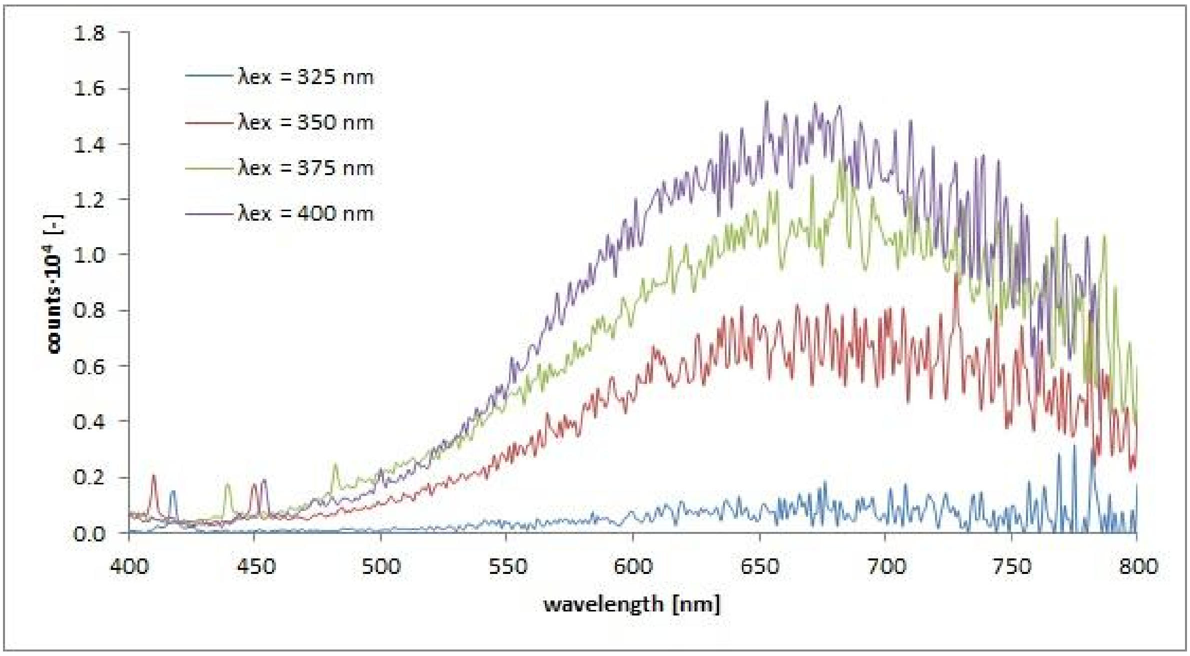

Fig. 5. The emission spectra of ZnO nanoparticles for various excitation wavelengths.
Source: Authors

The analysis of photoluminescence characteristics of ZnO NPs, and the results of computer simulation suggest that the optical transmittance for wavelengths above 430 nm should be as high as possible. For practical reasons, the authors considered application of the DC layer on the industrial type of thin-film, flexible solar cell. In Fig. 6 the external quantum efficiency of amorphous silicon (a-Si) of a solar cell by PowerFilm series MP3-37 is presented with optical transmittance of the layers obtained with spin speed of 4000 rpm and emission and excitation spectra of ZnO NPs. The emission excitation spectrum of ZnO NPs, which can be treated with some assumptions as absorption spectrum, matches the a-Si solar cell external quantum efficiency characteristic, as the solar cell is not sensitive in this range. The ZnO powder absorbs in the range of wavelengths 350-450 nm, in which the EQE for a-Si solar cell is low. Although the maximum of emission for ZnO NPs is shifted towards longer wavelengths, the value of external quantum efficiency of a-Si solar cell still exceeds 50% in this range, hence a DC layer based on ZnO NPs will potentially improve the efficiency of a-Si solar cell. The optical transmittance of all layers is more than 85% for the whole visible range.

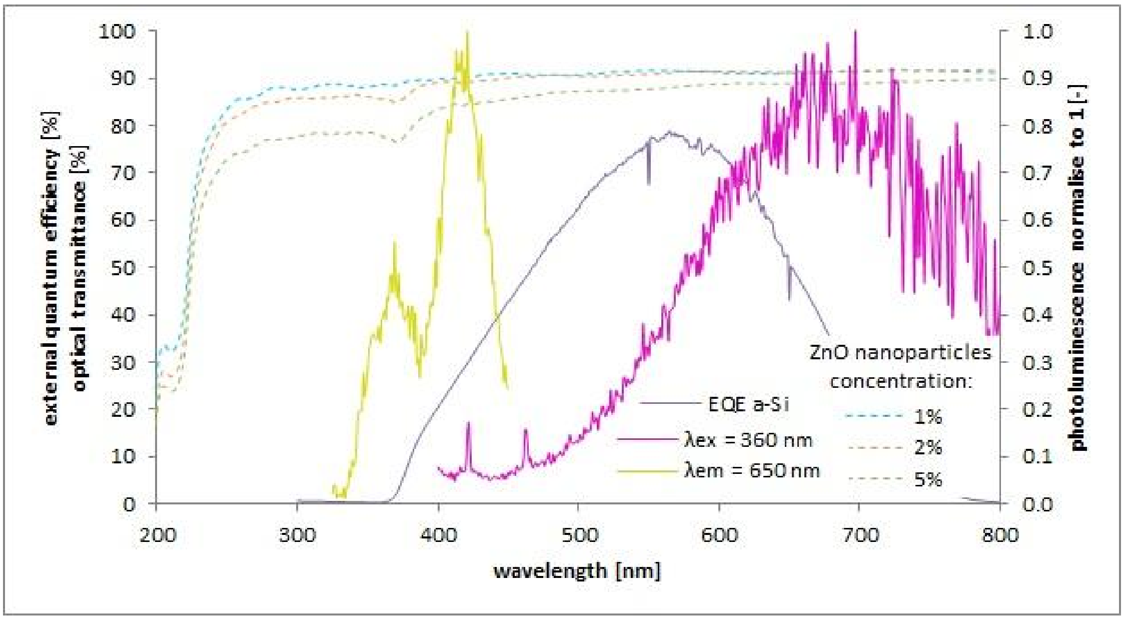

Fig. 6. The EQE of a-Si solar cell, the excitation end emission spectrum of ZnO NPs and optical transmittance of a layer with ZnO NPs in various concentrations for 4000 rpm spin speed .
Source: Authors

The emission spectra of DC layers with ZnO NPs are presented in Figs. 7-10 for various concentrations of ZnO. Interestingly, in the case of layers, intense blue emission is observed. The origin of the emission peak in the range of 400-470 nm is not completely understood. However it could be interpreted as emission coming from Zn interstitials states which are responsible for characteristic near-band-edge emission [27].

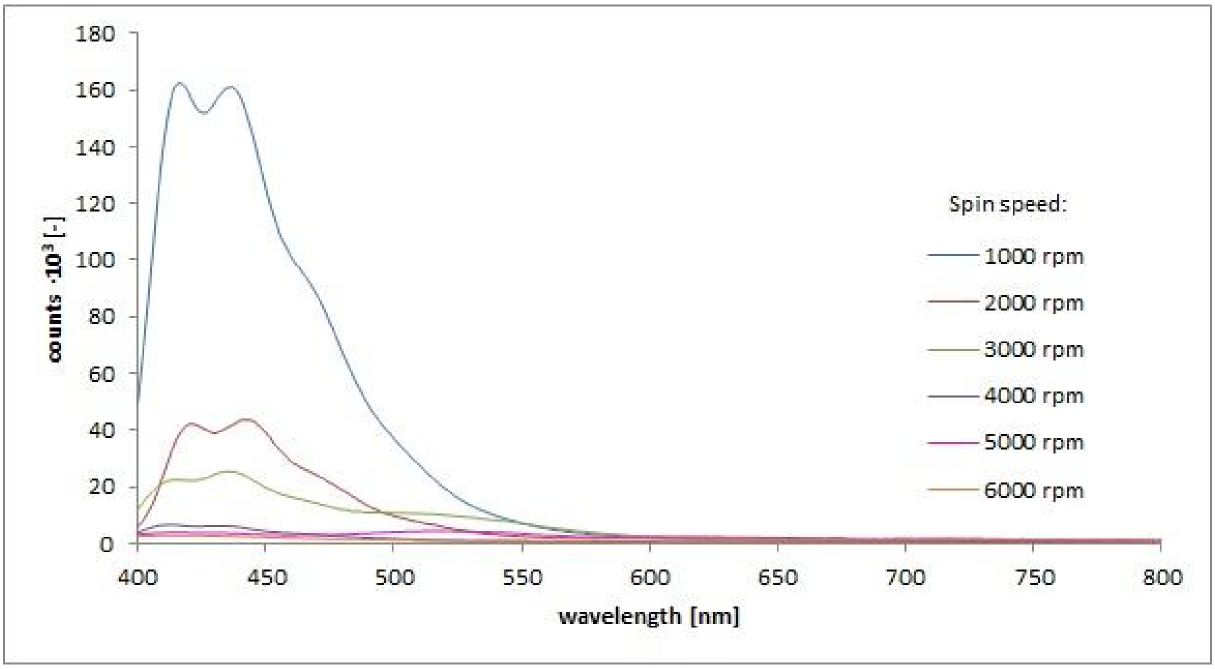

Fig. 7. The emission spectrum of down-conversion layer with ZnO NPs in 1% concentration.
Source: Authors

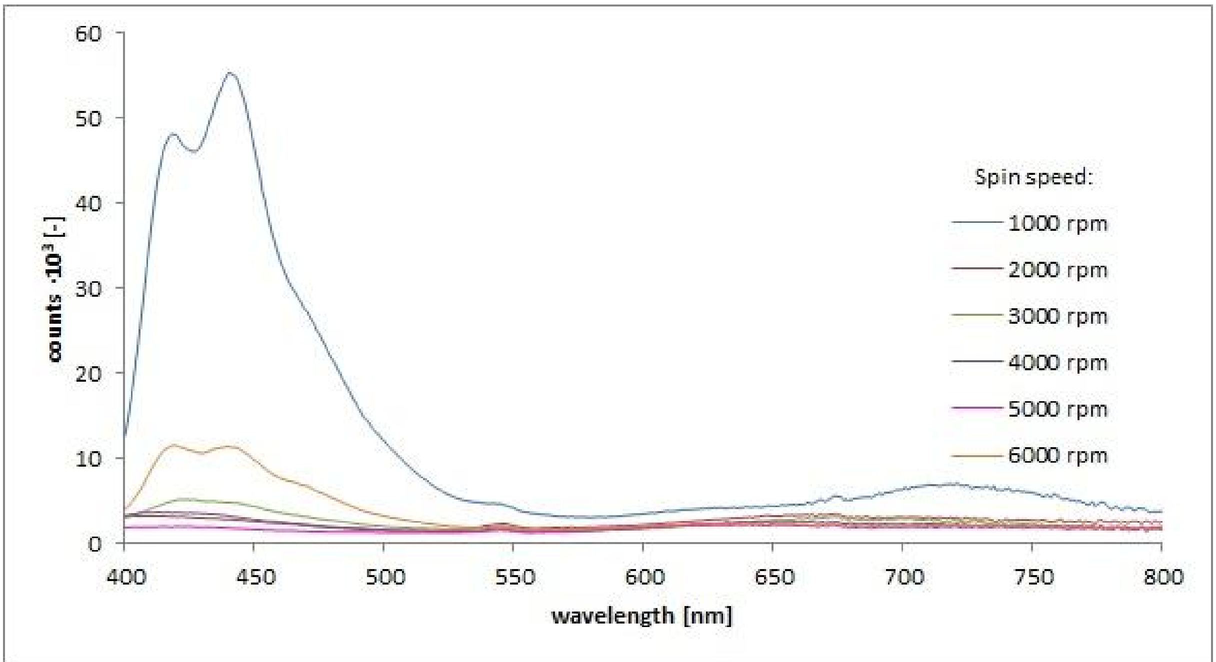

Fig. 8. The emission spectrum of down-conversion layer with ZnO NPs in 2% concentration.
Source: Authors

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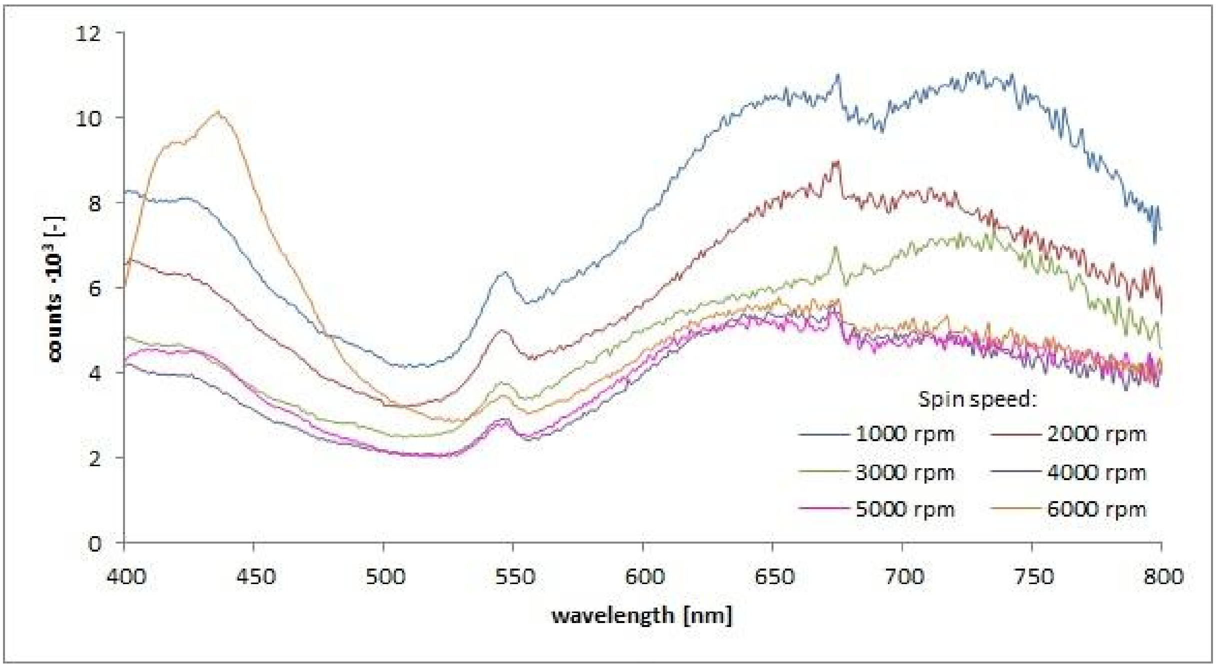

Fig. 9. The emission spectrum of down-conversion layer with ZnO NPs in 5% concentration.
Source: Authors

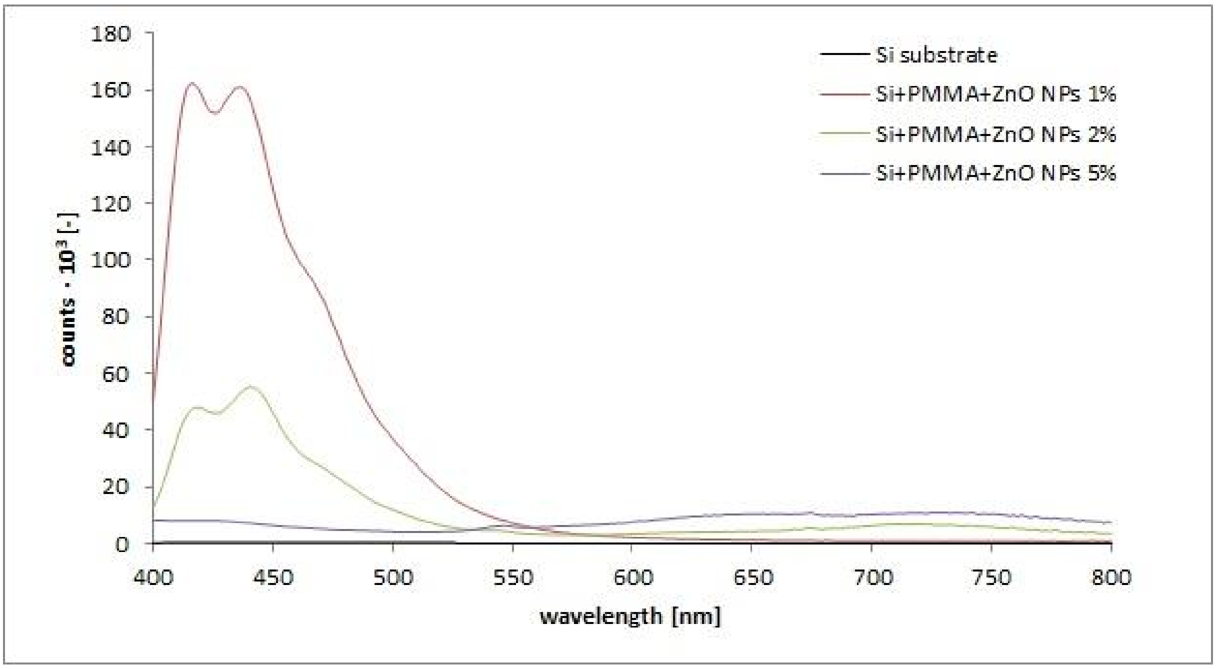

Fig. 10. The emission spectrum down-conversion layer with ZnO NPs of concentrations of 1%, 2% and 5% deposited at a spin speed of 1000 rpm.
Source: Authors

The results of optical transmittance and photoluminescence of DC layers with ZnO NPs in various concentrations suggested one of two different directions. The optical transmittance of the DC layer increases when the ZnO NPs concentration drops and the spin speed becomes higher. On the other hand, the emission spectrum of the DC layer is better with increased concentrations of ZnO NP and decreased spin speed. To meet the requirements for possibly high transmittance and high emission of the DC layer in the visible range, a compromise is needed. The golden mean seems to be a DC layer with 5% concentration of ZnO NPs fabricated at a spin speed of 3000 rpm (Fig. 11).

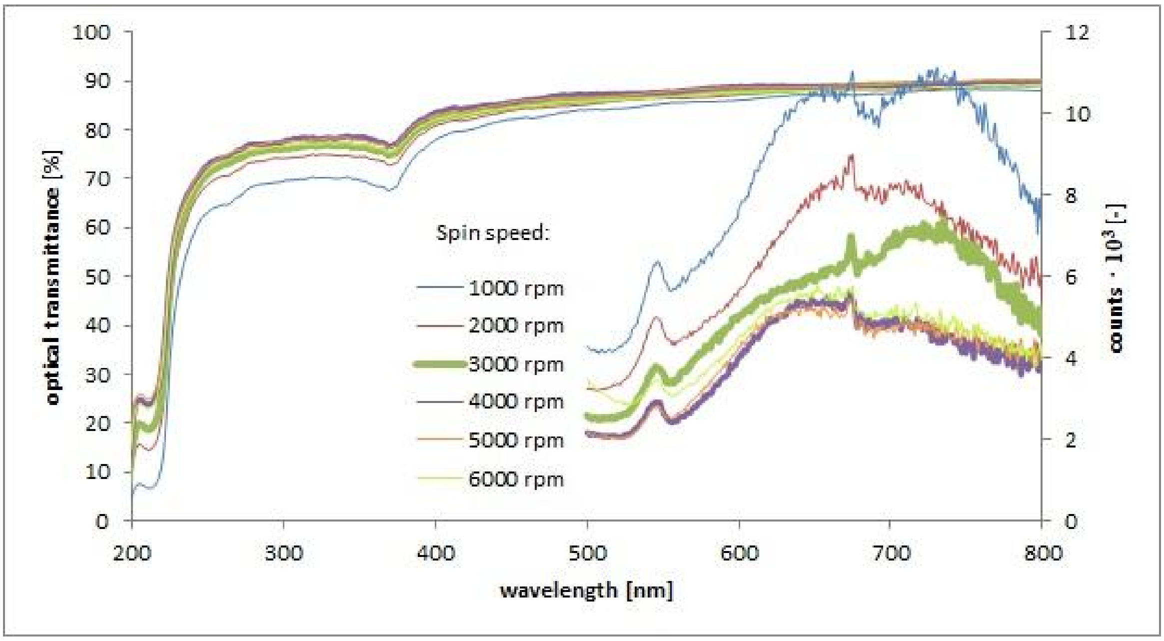

Fig. 11. The optical transmittance and emission spectra of down-conversion layer with ZnO NPs in the concentration 5% at a spin speed of 3000 rpm.
Source: Authors

The secondary electron image made with SEM for DC layers containing ZnO NPs in various concentrations are presented in Fig. 12. It can be seen that the morphology of the layers is similar and unrelated to concentrations of ZnO NPs. In Fig. 12d the exemplary surface profile is shown. It can be noticed that the surface of the DC layer is quite rough. Moreover, the SEM pictures show that ZnO NPs are grouped in small agglomerates, which are homogeneously distributed in the layer. The homogenous layer has more uniform parameters and will have an identical influence on the whole of the solar cell surface.

(a) (b) (c) (d)

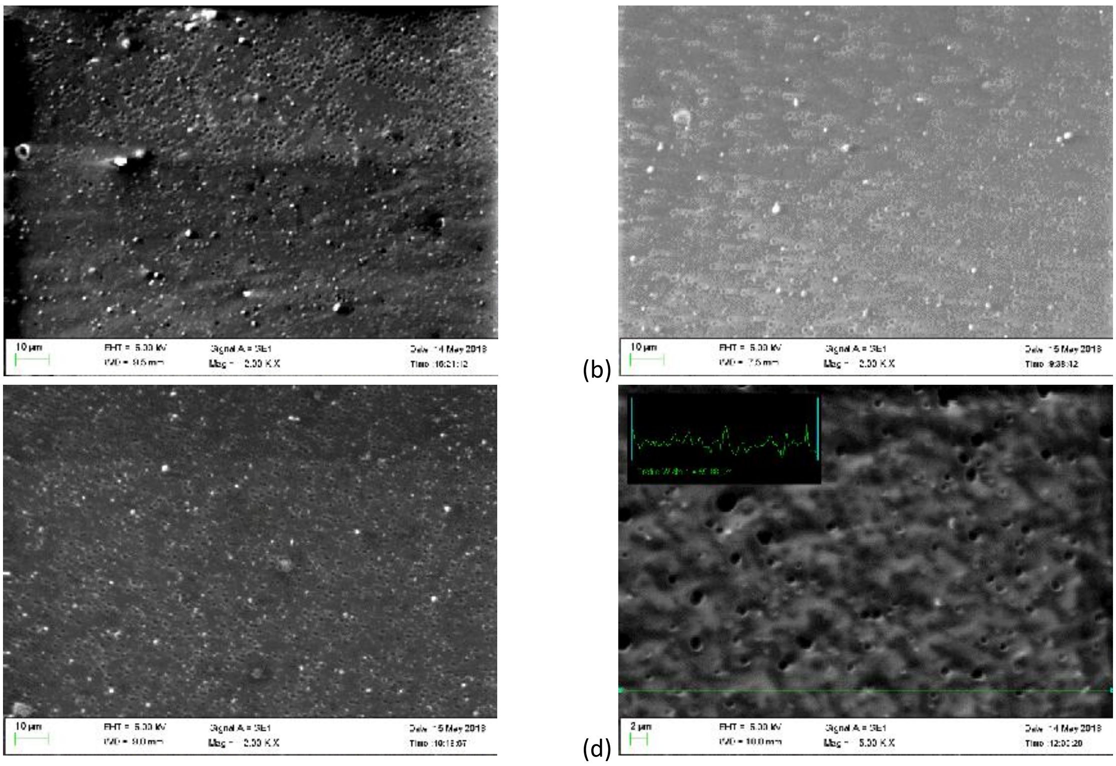

Fig. 12. The secondary electron (SE) SEM image of down-conversion layer with ZnO NPs in concentrations of (a) 1%, (b) 2%, and (c) 5%, deposited at 4000 rpm spin speed and (d) the exemplary surface profile of the DC layer with ZnO NPs in a 1% concentration deposited at 1000 rpm spin speed.
Source: Authors

The back-scattered electrons (BSE) SEM images for DC layers with ZnO NPs in various concentrations are presented in Fig. 13. Information about distribution of ZnO NPs in the PMMA base matrix in the DC layers is shown. The white points are ZnO NPs dispersed in the PMMA matrix (gray colour).

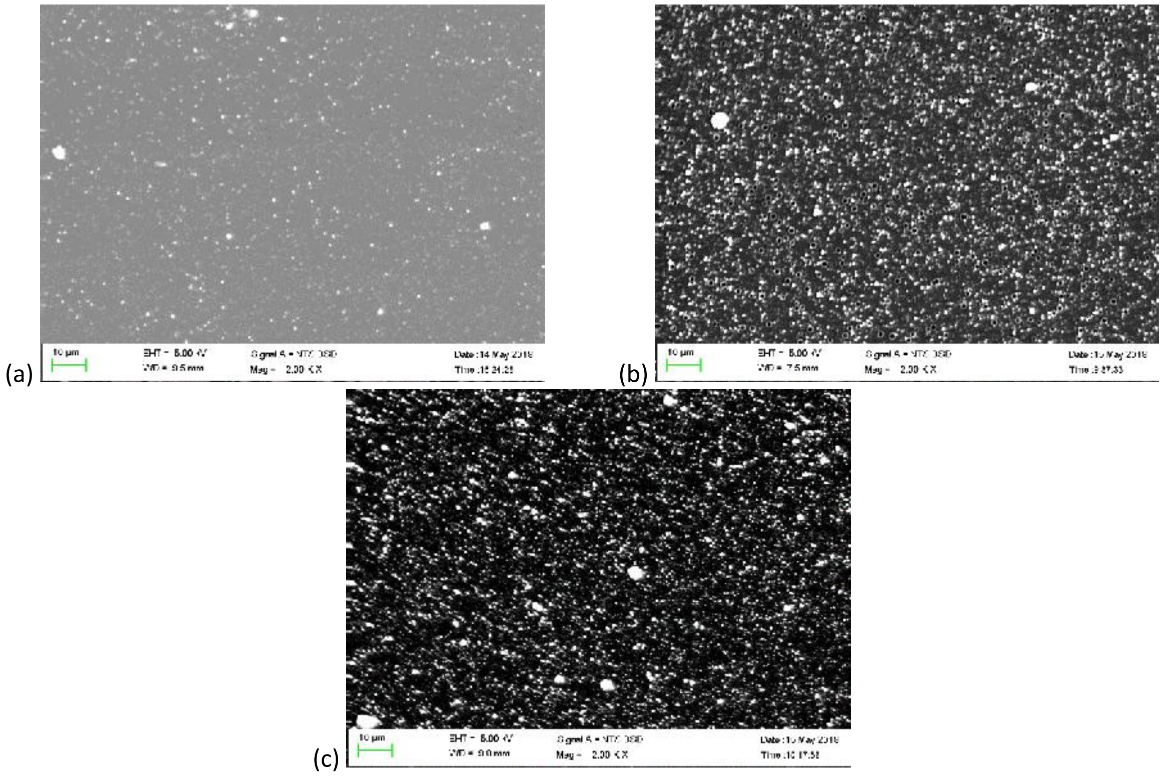

Fig. 13. Back-scattered electrons (BSE) SEM analysis of down-conversion layer with ZnO NPs in concentrations of: (a) 1%, (b) 2%, and (c) 5%, applied at 4000 rpm spin speed.
Source: Authors

Summary and conclusions

The photoluminescence effect could be successfully used in DC layers to increase solar cell efficiency. Based on Abrams et al. [10], Trupke et al. [11], and the results of computer simulation using SCAPS (Solar Cell Capacitance Simulator) software, the potential benefits of the DC layers are large. The photoluminescence properties and optical transmittance of DC layers are analysed as the two most important parameters. The luminescence quantum efficiency of the DC layer should be relatively high and the photoluminescence characteristic (excitation and emission spectrum) should match solar cell properties to increase the efficiency of the solar cell. In other words, the excitation spectrum should fall within the UV radiation and the emission spectrum should match EQE characteristic of a solar cell. The optical transmittance should be relatively high in the whole visible range.

The manufactured DC layers containing ZnO NPs dispersed in the PMMA matrix possess the desirable optical transmittance which exceeds 85% in the visible range for all layers, regardless of the concentration of ZnO NPs deposited at a spin speed of 4000 rpm or more. The emission spectrum of the DC layers achieves the highest values for higher concentrations of ZnO NPs when deposited at low spin speeds. As a compromise, a DC layer with a 5% concentration of ZnO NPs applied at 3000 rpm spin speed was chosen. As the next step, that DC layer will be applied on different photovoltaic structures and the basic parameters, including I-V and EQE characteristics of prototype solar cells with the DC layer will be examined.

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References

[1] S. Sanguinetti, M. Guzzi, M. Gurioli, 6 – Accessing structural and electronic properties of semiconductor nanostructures via photoluminescence, Characterization of Semiconductor Heterostructures and Nanostructures (2008) 175–208

[2] M. E. Sadat, M. K. Baghbador, A. W. Dunn, H. P. Wagner, R. C. Ewing, J. Zhang, H. Xu, G. M. Pauletti, D. B. Mast, D. Shi, Photoluminescence and photothermal effect of Fe3O4 nanoparticles for medical imaging and therapy, Applied Physics Letters 105 (2014) 091903-1-5

[3] T. Trupke, B. Mitchell, J. W. Webera, W. Mc Millana, R. A. Bardosa, R. Kroezea, Photoluminescence Imaging for Photovoltaic Applications, Energy Procedia
Volume 15 (2012) 135-146

[4] V. Kheraj, B. J. Simonds, A. Toshniwal, S. Misra, P. Peroncik, C. Zhang, Z. V. Vardeny, M. A.Scarpulla, Using photoluminescence to monitor the optoelectronic properties of methylammonium lead halide perovskites in light and dark over periods of days, Journal of Luminescence 194 (2018) 353-358

[5] C. K. Lo, Y. S. Lim, S. G. Tan, F. A. Rahman, A New Hybrid Algorithm Using Thermodynamic and Backward Ray-Tracing Approaches for Modeling Luminescent Solar Concentrators, Energies 3 (2010) 1831-1860

[6] A. Apostoluk, Y. Zhu, B. Masenelli, J.-J. Delaunay, M. Sibiński, K. Znajdek, A.Focsa, I. Kaliszewska, Improvement of the solar cell efficiency by the ZnO nanoparticle layer via the down-shifting effect, Microelectronic Engineering 127 (2014) 51-56

[7] K. Znajdek, N. Szczecińska, M. Sibiński, G. Wiosna-Sałyga, K. Przymęcki, Luminescent layers based on rare earth elements for thin-film flexible solar cells applications, Optik – International Journal for Light and Electron Optics 165 (2018) 200-209

[8] W. Shockley, J. K. Queisser, Detailed Balance Limit of Efficiency of p-n Junction Solar Cells, Journal of Applied Physics 32 (1961) 510-519

[9] H. J. Hovel, R. T. Hodgson, J. M. Woodall, The effect of fluorescent wavelength shifting on solar cell spectral response, Solar Energy Materials 2 (1979) 19-29

[10] Z. R. Abrams, A. Niv, X. Zhang, Solar energy enhancement using down-converting particles: A rigorous approach, Journal of Applied Physics 109 (2011) 114905-1-9

[11] T. Trupke, M. A. Green, P. Wurfel, Improving solar cell efficiencies by down-conversion of high-energy photons, Journal of Applied Physics 92 (3) (2002) 1668-1674

[12] D. Dexter, A theory of sensitized luminescence in solids, Journal of Chemical Physics 21 (5) (1953) 836-850

[13] M. B. De la Mora, O. Amelines-Sarria, B. M. Monroy, C. D. Hernandez, J. E. Lugo, Materials for downconversion in solar cells: Perspectives and challenges, Solar Energy Materials & Solar Cells 165 (2017) 59-71

[14] E. Klampaftis, D. Ross, K. R. McIntosh, B. S. Richards, Enhancing the performance of solar cells via luminescent down-shifting of incident spectrum: A review, Solar Energy Materials & Solar Cells 93 (2009) 1182-1194

[15] A. M. Gabr, J. F. Wheeldon, R. M. Beal, A. Walker, J. Sacks, R. M. Savidge, T. J. Hall, R.N. Kleiman, K. Hinzer, Modeling Down-Conversion and Down-Shifting for Photovoltaic Applications, Photovoltaic Specialists Conference (PVSC), 2012 38th IEEE (2012) 48-52

[16] T. Jin, S. Inoue, K. Machida, G. Adachi, Photovoltaic cell characteristics of hybrid silicon devices with lanthanide complex phosphor-coating film, Journal of Electrochemical Society 144 (11) (1997) 4054–4058

[17] N. Yao, J. Huang, K. Fu, X. Deng, M. Ding, M. Shao, X. Xu, Enhanced light harvesting of dye-sensitized solar cells with up/down conversion materials, Electrochimica Acta 154 (2015) 273–277

[18] W. He, T.S. Atabaev, H.K. Kim, Y.-H. Hwang, Enhanced sunlight harvesting of dye-sensitized solar cells assisted with long persistent phosphor materials, Journal of Physical Chemistry C 117 (2013) 17894–17900

[19] M.-L. Tsai, W.-R. Wei, L. Tang, H.-C. Chang, S.-H. Tai, P.-K. Yang, S.P. Lau, L.- J. Chen, J.-H. He, Si hybrid solar cells with 13% efficiency via concurrent improvement in optical and electrical properties by employing graphene quantum dots, ACS Nano 10 (2016) 815–821

[20] C.-C. Lin, H.-C. Chen, H.-V. Han, Y.-L. Tsai, C.-H. Chang, M.-A. Tsai, H.-C. Kuo, P. Yu, Enhanced efficiency for c-Si solar cell with nanopillar array via quantum dots layers, OSA – Optics Express 19 (S5) (2011) 825609–825606

[21] D.-C. Cheng, H.-C. Hao, M. Zhang, W. Shi, M. Lu, Improving Si solar cell performance using Mn:ZnSe quantum dot-doped PLMA thin film, Nanoscale Research Letters 8 (2013) 1–5

[22] H.-C. Chen, C.-C. Lin, H.-V. Han, K.-J. Chen, Y.-L. Tsai, Y.-A. Chang, M.-H. Shih, H.-C. Kuo, P. Yu, Enhancement of power conversion efficiency in GaAs solar cells with dual-layer quantum dots using flexible PDMS film, Solar Energy Materials & Solar Cells 104 (2012) 92–96

[23] V. Kumar, O. M. Ntwaeaborwa, T. Soga, Viresh Dutta, H. C. Swart, Rare Earth Doped Zinc Oxide Nanophosphor Powder: A Future Material for Solid State Lighting and Solar Cells, ACS Photonics 4 (11) (2017) 2613–2637

[24] K. Znajdek, N. Szczecińska, P. Czarnecki, M. Sibiński, Z. Lisik, Evaluation of polymer based zinc oxide nanoparticle layers for down-conversion application in thin-film photovoltaic structures, 2018 IEEE 45th Photovoltaic Specialists Conference (PVSC) (2018)

[25] N. H. Nickel, E. Terukov, Zinc oxide – a material for micro- and optoelectronic applications, Proceedings of the NATO Advanced Research Workshop on Zinc Oxide as a Material for Micro- and Optoelectronic Applications 194 (2004) 197–209

[26] R.-C. Wang, C.-P. Liu, J.-L. Huang, Single-crystalline AlZnO nanowires/nanotubes synthesized at low temperature, Applied Physics Letters 88 (2006) 023111-1-3

[27] K. Bandopadhyay, J. Mitra, Zn interstitials and O vacancies responsible for ntype ZnO: what do the emission spectra reveal?, The Royal Society of Chemistry Advances 5 (2015), 23540-23547

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AN INNOVATIVE METHOD OF ACTIVATING LIME WASTE. WASTE – SORBENT - PRODUCT

Abstract
The paper presents the production technology of sorbents for flue gas desulphurization with the wet limestone method, produced on the basis of limestone waste. The waste was subjected to comprehensive physicochemical tests and the following were studied: size distribution, chemical composition, morphology and reactivity. The analysed waste was subjected to electromagnetic activation to improve the sorption properties lost in the original process. The effect of the activation process was determined by comparing physicochemical properties of the waste before and after its activation. Based on the experience gained, an industrial installation was designed and manufactured industrial.

Key words
Limestone waste, electromagnetic mill, activation, sorbent, desulphurization.

Introduction

Calcareous wastes represent a significant group of waste compounds. It is estimated that in Poland about 1.5 million tonnes of waste is formed with a high calcium content. Such large amounts of waste of this type may constitute a source of calcium compounds for various industries. The industry that uses the large amounts of fossil limestone for flue gas desulphurisation is the energy industry. This branch of industry can become a potential recipient respectively of processed waste calcium compounds, especially given that a large increase in the demand for lime sorbents is expected as a result of the introduction of further emission limits. The introduction in Poland of the provisions of Directive 2010/75 / EU (IED) and the guidelines concerning the best available techniques (BAT) will tighten the sulfur dioxide emission requirements. This will particularly affect smaller installations that usually do not have a flue gas desulfurization system. For example, after a transitional period: for emitters in the range up to 100 MW, the emission limit value will fall from 1500 to 150 - 360 mg/Nm^3, while from 100 to 225 MW it will fall from 1500 to 80 - 200 mg/Nm^3[1][2]. Tightening the emission limit values for sulphur dioxide emissions means that their value will be several times smaller than at present. The necessity of such a large reduction in SO_2 emissions will cause a rapid increase in the demand for limestone in various forms, used for various methods of flue gas desulphurisation. Exploitation of the potential of waste calcium compounds would allow to partial meeting of the increase in demand for SO_2 sorbents caused by the new requirements and to protect natural limestone deposits. An example of waste that could meet the conditions for what are the limestones used in the desulfurization of flue gas, could be the calcium waste formed in the process of producing propylene oxide.

Materials and methods

The waste calcium compounds used for the study were taken from chemical plants using calcium hydroxide in the process of producing propylene oxide. These wastes arise in the chlorochridrone saponification process using calcium hydroxide and are in the form of a low-concentrated solution (0.3-0.4%) of $Ca(OH)_2$. A schematic diagram of the process of forming the analysed waste is shown in Figure 1. The waste produced in the presented process occurs in the form of: a filter cake directly from production and waste deposited in landfills.

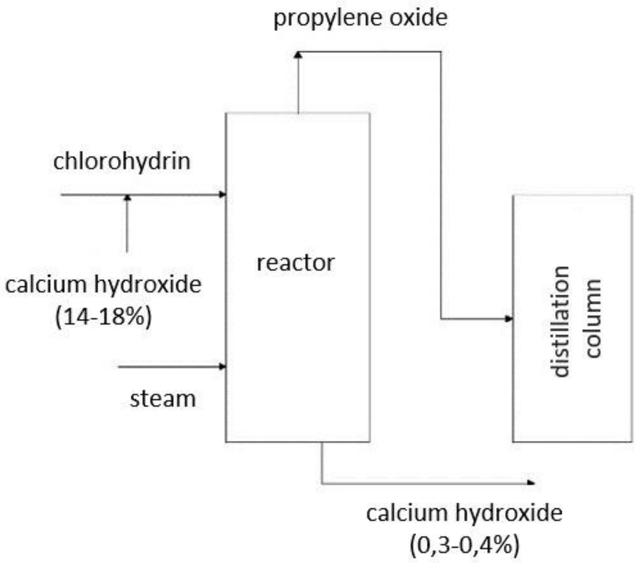


Fig. 1. The production process of propylene oxide
Source: Author's

The material for tests was taken both from the filter cake straight from the production, as well as from landfills on which the waste was deposited over a long period of time. For samples taken a series of physical and chemical analyses were made. The following parameters were analysed: moisture content, chemical composition, heavy metal content, granulometric composition and sorptive properties with respect to SO_2. Moisture content was determined according to PN-76/B04350 standard at 105^{o}C, chemical composition analysis was performed according to the PN-EN I96-2;1996 standard, whereas heavy metals were determined by ASA method according to the PN-ISO 8288;2002. Investigations of the granulometric composition of waste were made using the Mastersizer 2000 laser granulometer manufactured by Malvern Instruments Ltd. with a particle size range from 0.01 to 2000 µm. The value of the specific surface area was determined using the Blaine method. The tests of sorption properties were carried out, determining: the reactivity index Ri, the absolute sorption Ci and the conversion rate X for the dry mass of the waste. The reactivity index and absolute sorption were determined in accordance with the Alsthrom Propywe-Reactivity guidelines. The reactivity index were defined as the Ca/S molar ratio, which takes into account the Ca content before the test and the S content after the test. The absolute sorption index Ci is defined as the mass of sulfur [g] absorbed by the kilogram of the sorbent under test. The conversion rate was defined as the amount of moles of Ca that had reacted to $CaSO_4$ [3,4,5,6].

Experimental procedure

In the first stage of the research, waste samples were subjected to initial physicochemical analysis, determining their: moisture content, chemical composition, heavy metal content, granulometric composition and sorptive properties with respect to SO_2. In the next stage of the research, the samples were subjected to the activation process. For the activation of the calcium waste, an electromagnetic mill is used. The process of waste activation took the following course: the calcium waste from the feed tank was fed through the pump to the working chamber of the mill. In the working chamber, the material was subjected to mechanical treatment by rotating grinding media (grinding time about 10 sec) as well as the operation of a strong electromagnetic field (magnetic induction 1,2 T). In the working chamber the material was subjected to the action of chaotically rotating fine grinding elements which, acting on the feed, break down agglomerates and cracking and crushing of its grains. The product obtained after the activation process was gravitationally discharged into the product container.

The basic effect of the activation process is to increase the specific surface area of the activated waste particles. This surface increases as the diameter of the particles decreases, which translates into improved sulfur dioxide bonding properties. The specific surface of the particle is thus the surface of the reaction. Another way to increase the reaction surface in the area of the same fraction of particles is to develop their surface structure. A large number of small grinding elements and a high frequency of impacts on waste grains enable the crushing of the grain surface, increasing gaps and pores. After the activation, the sorption properties and granulometric composition were again determined using the same test procedures. The process of waste activation was carried out according to the patent "The method of sorbent preparation for the wet flue gas desulfurization process" [7].

Electromagnetic mill

An electromagnetic mill is a device that uses the phenomenon of a rotating magnetic field, under the influence of which small ferromagnetic grinding elements move chaotically inside the working chamber of the mill. The mill, as the main element of the electromagnetic activator installation, consists of two main parts: a grinding chamber with grinding elements and a stator with six windings. The grinding chamber is a non-ferromagnetic tube inside which small, ferromagnetic grinding elements move in the rotating magnetic field. The whole is a working area in which the material is subjected to mechanical, thermal and magnetic field treatment. With the increase of the magnetic induction value inside the working chamber, small grinding elements are introduced into an increasingly turbulent motion. The ferromagnetic grinder, under the influence of magnetic field induction, becomes a magnetic dipole with specific poles, attracted by this field with a specific force. Due to the small size and the appropriate shape and proportions of the dimensions, it is possible to achieve high acceleration and quickly achieve the maximum speed of grinder [8]. In connection with the very fast rotational movement of grinding media, the number of strokes of grinding elements per particles of activated waste is also significant. In addition, the grinding media working under the influence of magnetic induction and mutual collisions heat up, transfer heat to the substrate. A diagram of the construction of the electromagnetic activator and the view of the electromagnetic field exciter are shown in Figure 2. Use of the mill waste activation in the patent describes the electromagnetic "Device to activate the sorbents" [9].

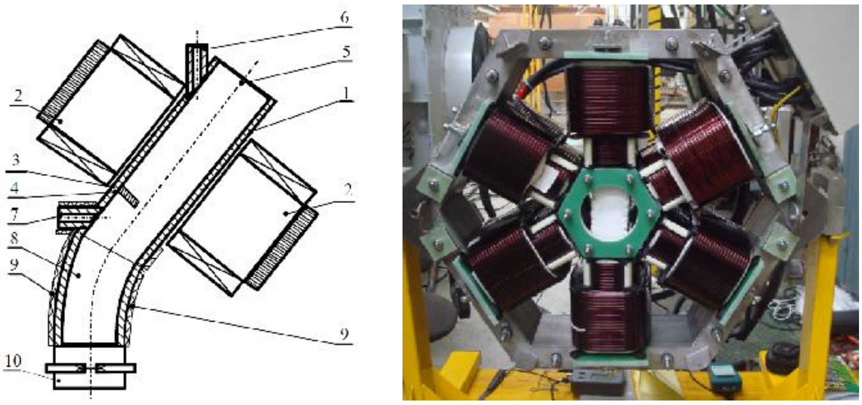


Fig. 2. Diagram of the construction of the electromagnetic activator (left). Description: 1 - working chamber, 2 - inductor poles, 3 - winding, 4-aperture grinding elements, 5 - charging hole, 6 - inlet hole, 7 - measuring force, 8 - product receiving segment, 9 - thermal insulation, 10 - connector for tight connection with the product receiving container and the physical model of the inductor (right).

Source: Author's

Results analysis

Research humidity showed a level of over 70% of its contents in the samples from landfills. Research on waste after production as a "filter cake" showed a moisture content at a level of 40%. The results of analyses of the chemical composition of waste are shown in Table 1, and the results of tests for heavy metals in Table 2.

Table 1. Average chemical composition of the tested samples (dry mass) [%].

No.	Component	Waste from the landfill		Filter cake	
		Mean values	Standard deviation	Mean values	Standard deviation
1	SiO_2	3.50	0.05	3.20	0.06
2	Fe_2O_3	1.20	0.02	0.98	0.02
3	Al_2O_3	1.75	0.01	1.73	0.05
4	CaO	49.4	1.20	51.2	1.43
5	MgO	2.24	0.24	2.27	0.21
6	SO_3	0.60	0.02	0.71	0.03
7	Ignition losses	31.4	1.58	27.6	1.87

Source: Author's

Table 2. Heavy metals content (dry mass) [mg/kg].

No.	Component	Waste from the landfill		Filter cake	
		Mean values	Standard deviation	Mean values	Standard deviation
1	Copper	0.003	0.0002	0.003	0.0003
2	Nickel	0.012	0.0007	0.013	0.007
3	Zinc	0.03	0.005	0.025	0.005
4	Chrome	0.001	0.0002	0.001	0.0003
5	Cadmium	0.001	0.0002	0.001	0.0002
6	Manganese	0.056	0.0005	0.053	0.0006
7	Lead	0.12	0.005	0.13	0.004

Source: Author's

In test samples about 50% of the content of calcium was found. In the waste from the landfill, 70% of it was calcium carbonate, the remaining part being calcium hydroxide and calcium oxide. In the case of the filter cake, more than 90% was calcium hydroxide. The tests of sorption properties were carried out, determining: the reactivity index Ri, the absolute sorption Ci and the conversion rate X for the dry mass of the waste. The results of the analyses carried out are presented in Table 3. Samples 1, 2 and 3 correspond to averaged sample taken from different landfills.

Table. 3. Results for reactivity indices

Sample	Parameters					
	R_i [mol/mol]		C_i [g/S kg]		X [%]	
	Mean values	Standard deviation	Mean values	Standard deviation	Mean values	Standard deviation
1	3.88	0.29	81	5.12	26	2.65
2	4.07	0.38	75	4.38	24	1.21
3	4.0	0.41	78	4.21	25	2.05
Filter cake	3.55	0.46	97	5.39	29	0.98

Source: Author's

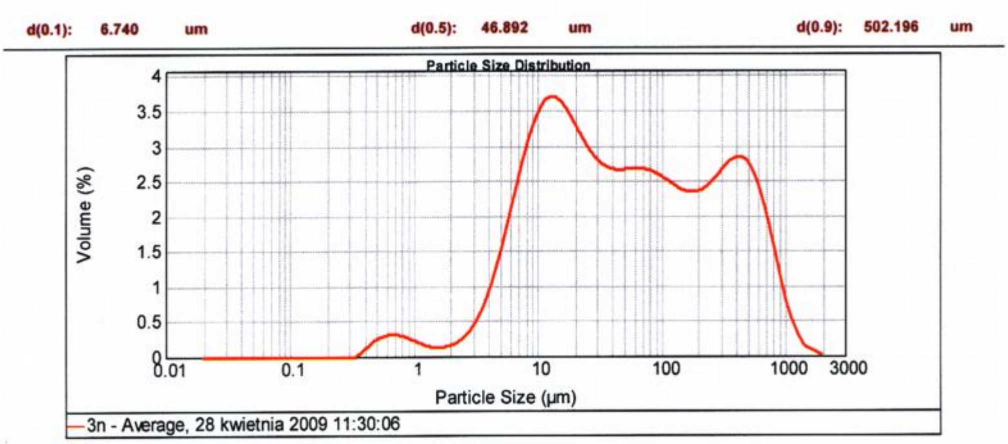
Before activating the reactivity rates were within the limits (3.55-4.07), according to the Alhstrom classification (Table 4), the waste calcium compounds were in a sufficient and good class.

Table 4. Scale of reactivity of sorbents

Evaluation of limestone	R_i	C_i
Excellent	< 2.5	> 120
Very good	2.5 - 3.0	100 -120
Good	3.0 - 4.0	80 - 100
Sufficient	4.0 - 5.0	60 - 80
Low quality	> 5.0	< 60

Source: [5,6]

Studies regarding the granulometric composition of waste were made using the Mastersizer 2000 laser granulometer manufactured by Malvern Instruments Ltd. with a particle size range from 0.01 to 2000 µm. The figure below presents an example of the analysis of the particle distribution of waste from landfill.



Size (µm)	Volume In %
0.020	
	44.89
35.000	
	4.39
45.000	
	8.91
75.000	
	4.93
100.000	

Size (µm)	Volume In %
100.000	
	10.93
200.000	
	6.56
300.000	
	9.31
500.000	
	8.85
1000.000	

Size (µm)	Volume In %
1000.000	
	1.23
2000.000	

Fig. 3. Particle size distribution waste collected from the landfill.
Source: Author's

The particle distribution of the waste was in the range of 0.02 to 2000 µm, with the advantage of the grains in the range of 0.02 to 35µm (ca. 45%). The average diameter of grains was in the range 35.89 - 46.89 µm, while the surface area ranged from 0.474 to 0.545 m^2/g, the standard deviation was 0,04 m^2/g

The results of the research have confirmed that the waste calcium compounds after the production of propylene oxide show favourable physico-chemical properties, predisposing them for use as sorbents of sulfur dioxide. However, due to the decreased reactivity and unfavourable sorbent injection process, the particle size distribution requires proper pre-treatment (activation).

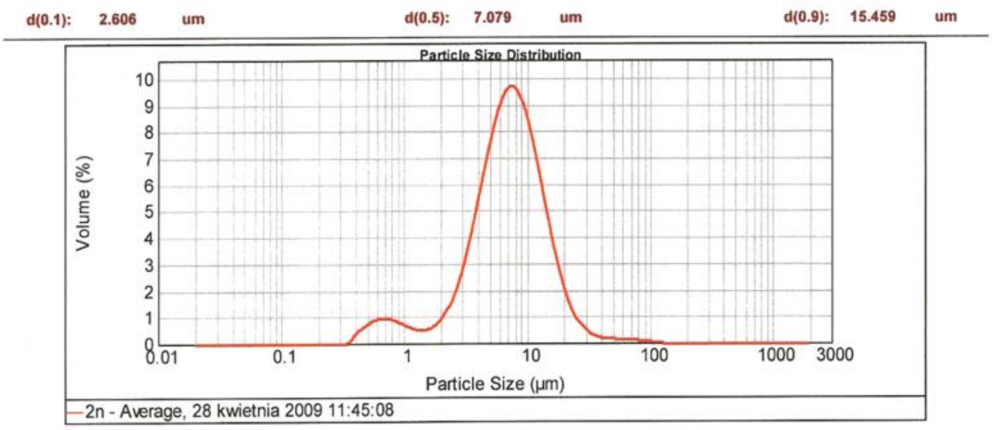
After the activation, the sorption properties and granulometric composition were again determined using the same test procedures as in the initial tests. Table 5 and Figure 4 present examples of results of investigations of activated waste.

Table 5. Results for reactivity indices samples after activation

Sample	Parameters					
	Ri [mol/mol]		Ci [g/S kg]		X [%]	
	Mean values	**Standard deviation**	**Mean values**	**Standard deviation**	**Mean values**	**Standard deviation**
1	2.91	0.39	101.25	6,18	34	1.68
2	2.89	0.43	97.50	4.83	35	2.73
3	2.76	0.52	102.18	5,27	36	2.79
cake filter	2.65	0.41	109.30	6.39	39	1.43
calcium hydroxide	2.23	0,38	129.00	5.49	45	1,05

Source: Author's

After activation, reactivity ratios reached a value of 2.65 - 2.91 and accordance with the Alhstrom's classification (table 4) were in the class, very good. Particle distribution of the waste was in the range of 0.02 to 100 μm, with the majority of the grains in the range of 0.02 to 35μm (ca. 98%). The average diameter of grains was in the range 6.09 - 7.09 μm. While the specific surface area ranged from 1.44 to 1.54 m^2/g, the standard deviation was 0.05 m^2/g.



Size (μm)	Volume In %
0.020	
35.000	98.91
45.000	0.36
75.000	0.50
100.000	0.17

Size (μm)	Volume In %
100.000	
200.000	0.05
300.000	0.00
500.000	0.00
1000.000	0.00

Size (μm)	Volume In %
1000.000	
2000.000	0.00

Fig. 4. Particle size distribution samples after activation.
Source: Author's

Summary of the analysis results

When comparing the results of the analysis of lime waste before and after the activation process, we can see a significant improvement in the parameters relevant for the SO_2 sorption process. Analysing the particle size distribution of waste, we can see that it was characterized by the following data: specific surface area 0.474 - 0.545 m^2/g, before activation and 1.44 - 1.54 m^2/g after activation. Activation allowed for the development of a specific surface area of 300%. The average diameter of grains decreased from the horizontal 35.89 - 46.89 μm, before activation to 6.09 - 7.09 μm after activation. The value of the reactivity index before activation fluctuated in the range from 3.55 to 4.07 (sufficient and good class). After the activation process, the reactivity rates ranged from 2.65 to 2.91 which classifies them as very good. In all cases, there has been an increase in sorption properties, which ranged from 33 to 44%. Despite activation, it was not possible to achieve reactivity as for pure calcium hydroxide. The result was lower by 18 to 30%.

The obtained results of analyses indicate, that waste calcium compounds subjected to activation in an electromagnetic mill can be used as a full-value sorbent in the wet flue gas desulfurization method. Confirmation of the possibility of using the potential of lime waste as a sorbent was achieved. It allowed to carrying out of design works, as a result of which was an industrial installation of limestone waste activation, using the electromagnetic mill technology.

Industrial research

To verify the results obtained and the correctness of the design of the devices, an industrial test of flue gas desulfurization with the use of activated waste was carried out. The test was divided into two parts. In the first part of the research, data were collected to create a comparative database. The process data for flue gas desulfurization using classical calcium hydroxide was collected. In the second part of the research, an electromagnetic mill was installed next to the intermediate tank of whitewash. The waste from landfills was delivered by car transport. Dosing to the mill was carried out using a pump and a flexible hose. The activated waste entered the intermediate tank and then the scrubber. Figure 5 shows the process of waste activation in industrial conditions.

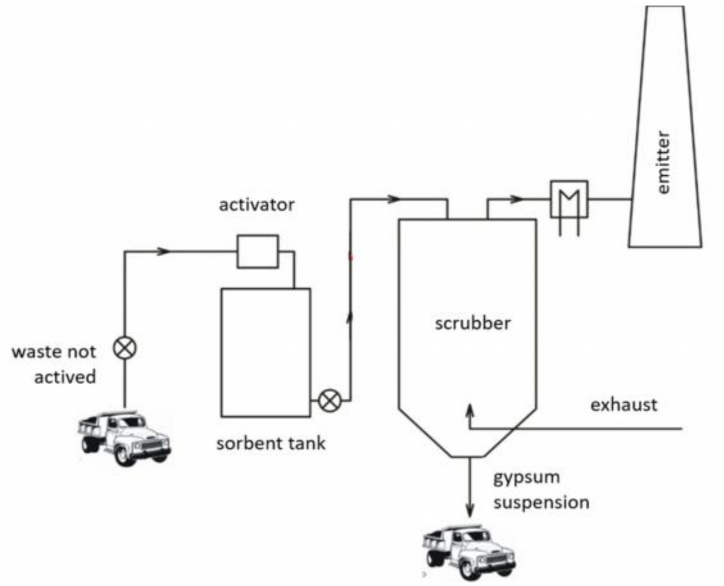


Fig.5. Process activation
Source: Author's

During the test, efficiency of flue gas desulphurisation was obtained at 77.81%, which was higher than the efficiency obtained in comparative studies (70.72%). In addition, the consumption of sorbent activated during the tests was lower by 25% than the consumption of calcium hydroxide, and thermal load boilers wavered within 5%. The obtained results were definitely better than earlier estimates. It was assumed that a comparable efficiency of flue gas desulphurisation would be obtained, but at about 20% increased stream of used waste in relation to calcium hydroxide. The results obtained from the industrial trial considerably surpassed expectations. A higher level of the efficiency of flue gas desulphurisation was obtained, with a 25% lower stream of activated sorbent, compared to the use of classical sorbent. In Figure 8, a view of the installation of waste limestone activation connected to a sorbent tank is shown.

Fig. 6. Installing the activator on the real object
Source: Author's

Summary

Increased consumption of calcium sorbents caused by successive tightening of SO_2 limits may become a stimulus for attempts to use waste calcium compounds, as sorbents in the different methods of flue gas desulfurization. As has been shown, this type of waste can become a full-value sorbent. Only the process to restore them to the original sorption properties lost in the processes of their original use is necessary. An example of such a process may be, as presented in the article, the process of activation based on the innovative technology of an electromagnetic mill. This technology makes it possible to transform stored waste in a technologically simple way so that it can be re-used. The reuse of waste as SO_2 sorbents brings a number of environmental and economic benefits.

- Strain off the environment by reducing the amount of waste deposited and the resulting savings associated with the costs of its storage.
- Savings associated with the lack of buying fossil limestone, and thus the protection of the natural deposits.

The use of waste sorbents in the wet flue gas desulfurization method allows us to connect the positive aspects of the liquidation of the landfilled waste, with simultaneous reduction of the sulfur oxides emitted into the atmosphere. As a final result, giving a commercial product which is synthetic gypsum. The results of trials of desulfurization and the benefits resulting from the application of the activated waste, enabled the industrial implementation of innovative lime waste activation technology.

Acknowledgements

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References

[1] *Dyrektywa Parlamentu Europejskiego i Rady 2010/75/UE z dnia 24 listopada 2010 r., w sprawie emisji przemysłowych - IED, (zintegrowane zapobieganie zanieczyszczeniom i ich kontrola).* http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:334:0017:0119:PL:PDF

[2] *Decyzja wykonawcza komisji (UE) 2017/1442 z dnia 31 lipca 2017 r. ustanawiająca konkluzje dotyczące najlepszych dostępnych technik (BAT) w odniesieniu do dużych obiektów energetycznego spalania zgodnie z dyrektywą Parlamentu Europejskiego i Rady 2010/75/UE*
http://eurlex.europa.eu/legalcontent/PL/TXT/?uri=uriserv:OJ.L_.2017.212.01.0001.01.POL&toc=OJ:L:2017:212:TOC

[3] Szymanek A.: *Sorbenty z popiołów. Cz. II. Mokre odsiarczanie spalin*, Ochrona Powietrza i Problemy Odpadów, 2008. nr 1, 17-24.

[4] Szymanek A., Nowak W.: *Mechanically activated limestone*, Chem. Process Eng., 2007, 287,127-137

[5] Wytyczne Alsthrom Propywe-Reactivity index. Alsthrom Propywer 1995.

[6] Szymanek A. *Badanie modyfikowanych sorbentów wapniowych do odsiarczania spalin*, praca doktorska, Politechnika Wrocławska, Wrocław 2000.

[7] Szymanek A., Szymańska J., Szymanek P.*, Sposób przygotowania sorbentu do procesu mokrego odsiarczania spalin*, PL 216869 B1

[8] Sosiński R., Szczypiorowski A., Szymanek P., Nowak W.: *Aspekty wykorzystania młyna elektromagnetycznego w rozwoju węglowych technologii energetycznych*, 24-Międzynarodowa Konferencja „Węgiel", Pittsburgh 2007

[9] Szymanek A., Szymańska J., Szymanek P.: *Urządzenie do aktywacji sorbentów,* PL 216912 B1

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QUALITY EVALUATION OF IRON CASTING EN-GJL-200 PRODUCED ON THE DISAMATIC LINE

Abstract
This article discusses the issues concerning the quality of casting surface with a small unit weight manufactured on the Disamatic automatic casting lines in a flaskless mould with a vertical parting line. The research was conducted in manufacturing conditions in one of the casting facilities in the country. The identification of casting defects for a monthly manufacturing cycle was made and agreed that the main causes of scrap casting are defects on the raw surface: lumps of moulding sand which after removal form cavities and draws as well as defects of gas origin such as blowholes. There are also defects of form namely short runs. In the later part of the work, the research results of the properties of moulding sand were presented and casting defects were selected the occurrence of which is connected with the quality of moulding sands.

Key words
grey cast iron, casting defects, sand mould

Introduction

The occurrence of casting defects or using the terminology of ISO standards of non-compliance, is directly related to the design and implementation of the production process, whose components are determined by a number of material and technological factors [1]. Depending on the cast alloy grade, the casting technology used, the casting dimensions and the degree of its complexity during production the shapes defects may be dominant, defects of the raw surface, discontinuity, internal defects and material defects classified in the PN-H-83105 [2]. Although gray cast iron foundry technology on automatic DISA lines has been optimized to a very high degree, the problem of casting defects always appears and especially at the stage of implementing a new range for mass production. Proper running of the production line requires continuous control of the process parameters, which periodically undergo dynamic changes. Maintaining these parameters within strictly defined standards does not ensure complete elimination of foundry defects. The final quality of castings produced by the discussed technology depends mainly on the metallurgical quality of liquid cast iron, moulding sand properties and the course of flooding processes, solidification, cooling and knocking out mould casts [3,4]. This article focuses mainly on foundry defects, whose origin is potentially related to the quality of moulding sand and physicochemical processes occurring at the cast-form interface [5]. It should be noted that degree of lack of castings in the foundry in which the research was carried out is insignificant, which results from its high engineering level.

The processes that occur at the phase boundary between the moulding sand - casting alloys largely determine the quality of the castings. The cause of such surface defects as metal penetration, pinholes porosity, surface roughness or burn-on is the interaction of moulding sand and liquid metal [6]. In the processes running at the phase boundary, molding sand - liquid metal the gas phase plays a significant role. The quantity and composition of gases which are formed at the phase boundary between moulding sand and liquid metal have an important influence on the character of the atmosphere in the mould, which consequently leads to such defects of castings as: pinholes porosity and blowholes [5]. Casting defects are unavoidable during foundry processes and although the foundry is constantly improving the quality of its products, it is not possible to eliminate 100% of foundry defects. The aim of the research was to analyze the parameters of molding sand in relation to the quality of EN-GJL-200 cast iron castings manufactured on the Disamatic line.

Materials and methods

The tests were carried out on gray cast iron EN-GJL-200 with a unit weight not exceeding 1 kg and wall thickness within 20 ÷ 30 mm, hereinafter referred to as Detal. The molds were made by high pressure method on Disamatic automatic casting lines in flaskless mould with a vertical dividing plane. The cast iron was smelted

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in a blast furnace with a heated blower ending with a continuous ingot casting line. Pouring moulds with liquid metal was carried out using a stopper ladle. After pouring, moulds were cooled and transported to multi-purpose rumblers. After cleaning the surface of the castings, they were subjected to quality control to determine compliance with the requirements. The tests used the names specified in the PN-H-83105. The second part of the research concerned the measurement of technological properties of moulding sands. The properties such as: compression strength, permeability, moisture content, compactibility, return massmoisture content, active bentonite content in moulding sand and content of coal dust (ignition losses). The tests were carried out for refreshed moulding sand and return mass. Refresh moulding sand samples were taken from the sand bin above the moulder's automat DISA I and DISA II from three different points. However, floor sand mould samples were taken from the end of the conveyor at the sand treating plant. All tests were carried out at the Factory Laboratory on the basis of Polish standards.

Compression strength tests were carried out using the LRu device in accordance with PN-83 / H-11073. Permeability measurement was performed on the LPiR device according to the PN-80 / H-11072 standard. Moisture content tests were carried out on the basis of BN-75 / 4024-06. Compactibility tests were performed based on the BN-76 / 4024-22 standard. The content of coal dust was determined on the basis of PN-91 / H-11008. The content of active clay was determined according to the BN-77 / 4024-16 standard. Samples for testing were made in accordance with PN-83 / H-11070 and PN-80/H-11073.

Results

The main cons of castings, which are repetitive in this grade of cast iron, are the following: short run casting, blowhole, lumps of moulding sand which after removal form cavities and draw. Sample images of the disclosed defects are shown in Figures 1-4.

Fig. 1. Photo of a casting defect - lumps of moulding sand which after removal form cavities

Source: Author's

Fig.2. Photo of a casting defect – blowhole

Source: Author's

Fig. 3. Photo of a casting defect - short run casting

Source: Author's

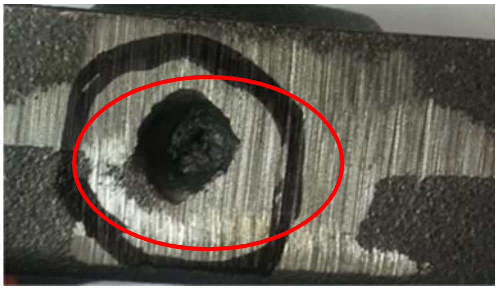

Fig. 4. Photo of a casting defect – draw
Source: Author's

In the whole production range of Detal, the number of defects is less than 5% and the most significant discrepancies can be included: blowhole and lumps of moulding sand which after removal form cavities. This relationship was depicted in the graph (Fig. 5), which represents the number of non-conformities detected on 8681 manufactured Detals per month. The number of defects is low, but the foundry still tries to eliminate the causes of the emerging defects.

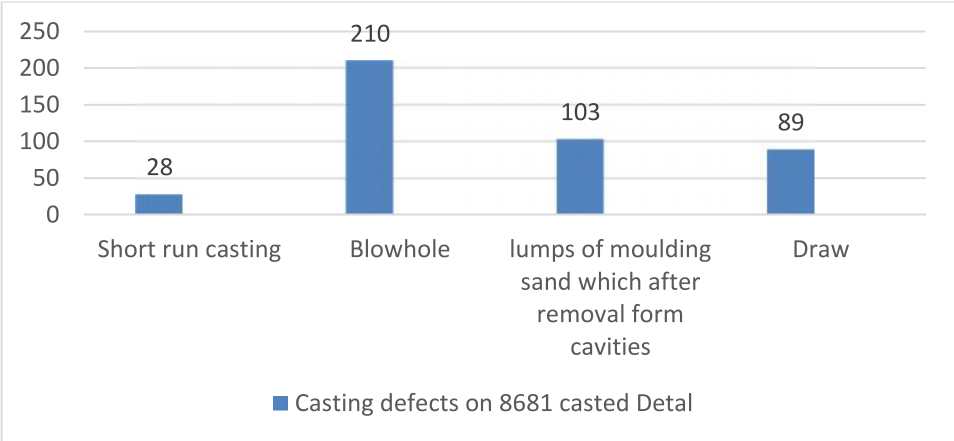

Fig. 5. Graph of the number of casting defects to the number of manufactured elements
Source: Author's

In order to analyse potential causes of defects, a closer assessment of the moulding sand parameters was made. Tested moulding sand was refreshed in the speedmuller MP-090L with the following composition: 95% circulation moulding sand, 0.5 ÷ 1% bentonite, 3% fresh moulding sand and 2.5% water. The moulding sand tests were carried out on the same day as the Detal casting and the results are presented in Table 1.

Table 1. Parameters of moulding sand - average values

Research day	**Moisture content, %**	**Permeability, m/Pa*s**	**Compression strenght, N/cm^2**	**Compactibility, %**	**Return massmoisture content , %**
1	2,7	280	18,50	42	Input of the return mass:0,2 Return mass output:0,4
2	2,9	260	19,83	42	Input of the return mass:0,6 Return mass output:0,7
3	3,0	260	19,50	35	Input of the return mass:0,6 Return mass output:0,6
4	3,0	250	19,63	44	Input of the return mass:0,8 Return mass output:0,7

Source: Author's

Moisture content test results were close to the optimal value, approx. 3% however, the worrying result is themoisture content of the return mass, which is too low. The optimum return mass parameters for this type of casting should be in the range of 1-1.5%. Nevertheless, the results of compactibility are within limits but they are too close to the upper limit of the standard, which may have a bearing on the quality of the castings. Fig. 6. shows the averaged contents of active clay and coal dust in the moulding sand in the subsequent production days of Detal.

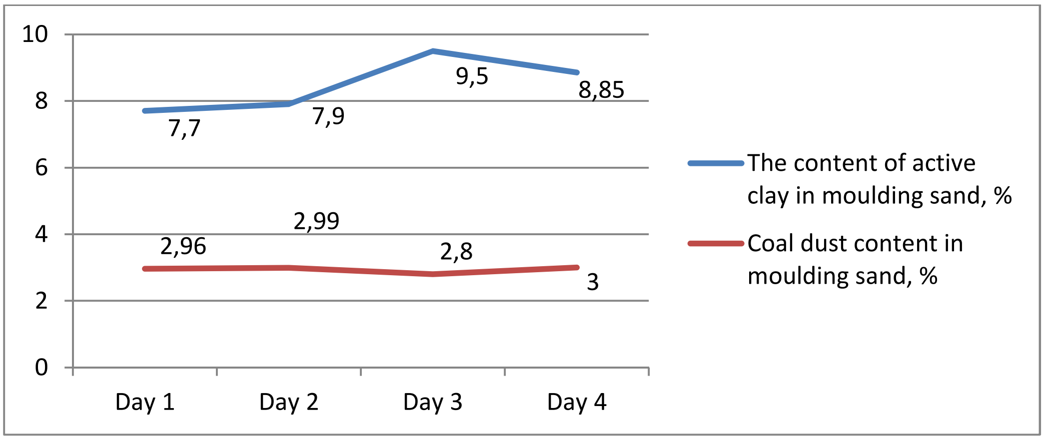

Fig. 6. Graph of change in the content of active clay and coal dust in moulding sand
Source: Author's

Coal dust added to the moulding sands ensures the smoothness of the casting surface and also prevents scorching of the mass into the casting. Such properties have dust from hard coal from which, when the mould pouring temperature is increased, bright coal is released. The requirements for coal dust are included in the PN-91 / H-11008 and present the following contents: water <2.0%, volatile matter: 30 ÷ 40%, ash <4.0%, sulfur <0.8%, bright coal> 9.0% [7,8]. After analysing the graph, it appears that the content of coal dust in the tested moulding mass remains at the level of 3% and falls within the permissible range of 2.0 ÷ 4.5%.

The content of active clay is of significant importance to obtain a mould with the desired strength. Pouring liquid metal into the mould several times deactivates part of the bentonite, which may be the result of inactive dust formation, which in turn leads to a deterioration of moulding sand properties [9]. The graph shows that the content of active clay is ~ 9% and this result is too high compared to the optimal overall values of 7-8%. However, the foundry in which the tests were carried out achieves the appropriate quality of casting with such a content of active clay.

The tests showed, that the average values of the technological parameters of the moulding sand are generally within the permissible limits of the relevant standards, the only exception is the test results for return mass moisture content. Despite all efforts, there are recurring foundry defects in the castings, the causes of which may be related to local mass heterogeneity, overheating of some areas of the mold cavity, as well as physicochemical interactions at the contact area mould and cast, during the cooling process and solidification of casting. The high pouring temperature, often technologically necessary, results in rapid burning of coal dust and is the reason for the inferior surface quality of the castings. As a result of its interaction, the deactivation of bentonite is also faster and therefore it is necessary to intensively refresh the moulding sand. In contact with liquid metal the carrier of bright coal decomposes. In a perfect condition, the bright coal in a crystalline form with a high degree of disintegration and dispersion is released. This is accompanied by a reductive atmosphere. The carbon is disengaged to form a coating on all, even physico-chemically inactive surfaces of the mould cavity and core surfaces. Excessive burning of coal dust on the upper surfaces of the mould cavity, as well as in the areas of the heat centres of the casting, unfortunately creates a danger of founding defects of gas origin. The source of blowholes revealed in the studies may also be: air trapped in the mould during pouring into moulds caused by turbulence during the metal flowing through the pouring- gate and air suction into the cavity of the mould, as well as insufficient de-aeration of the mould, too strong moulding sand compactibility, gases emitted from the core after pouring the mould - improper proportions of resins used to make the cores and too much moisture in the mould. Other reasons may be pouring into mould from too great a height or the inadequate pouring temperature of the mould. Draw is caused by the contraction of metal alloys during cooling and solidification. This defect is most often created in the areas of heat centres of the casting and this is often caused by too high a pouring temperature of the mould. Short run casting arises as a result of: a too low pouring temperature, the wrong way of mould pouring, too small / large stream or pouring with breaks, too little metal in the ladle, an inadequate permeability . Lumps of moulding sand which after removal, form cavities can also be formed by burning a mould or core, which is caused by a small amount of coal dust in the moulding sand, as well as during folding and the step drift of mould packages on the production line.

Conclusions

After the tests were carried out, the occurrence of repeated casting defects was observed despite the properties of moulding sand that were within the norms. The main non-conformities when casting gray iron cast products include: short run casting, blowholes, lumps of moulding sand which after removal, form cavities and draw. After the analysis, it appears that the most frequently occurring discrepancies are: blowholes and lumps of moulding sand which after removal form cavities. In the case of an external blowhole, the causes are gases trapped in the mould. This may be due to insufficient de-aeration of the mould or too much densified moulding sand, which is reflected in the results.

The lumps of moulding sand which after removal form cavities can be caused by the wrong relation between the amount of bentonite and the amount of water and also by the low moisture content of the return mass, which can be supported by the results for this parameter.

References

[1] PN-EN 1561/2012 Odlewnictwo-Żeliwo szare

[2] PN-85/H-83105 Odlewy – Podział i terminologia wad

[3] Lewandowski J.L., 1997, Tworzywa na formy odlewnicze, Wydawnictwo Akapit, Kraków

[4] Kościówko H., Wyrwicki R., 1996, Metodyka badań materiałów ilastych, Państwowy Instytut Geologiczny Warszawa, Wrocław

[5] Holtzer M, Zych J., 1997, Zjawiska zachodzące na granicy faz masa formierska-ciekłe żeliwo a jakość powierzchni odlewów, Krzepnięcie Metali i Stopów, nr 33

[6] Holtzer M., Przegląd Odlewnictwa, 1994, nr 6, 2014-217

[7] Lewandowski J.L., Solarski W., Zawada J., Toksyczność masy formierskiej z bentonitem zawierającej pyl węglowy, Krzepnięcie Metali i Stopów, Nr 35, 1998 PAN- Oddział Katowice PL-ISSN 0208-9386

[8] PN-91/H-11008 Odlewnicze materiały formierskie- pył węglowy

[9] Michta-Stawiarska T., 1998, Trudności w stabilizacji właściwości klasycznych mas formierskich, Krzepnięcie Metali i Stopów, Nr 35, P AN - Oddział Katowice PL. ISSN 0208-9386

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SELECTED AIR POLLUTANTS IN URBAN AND RURAL AREAS, UNDER THE INFLUENCE OF POWER PLANTS

Abstract
The operation of large power plants, including power stations, and combined heat and power stations, causes the emission of significant amounts of gaseous pollutants into the environment. As a result, in the urban and agricultural areas occurs a pollution of undesirable gaseous substances, such as nitrogen and sulfur oxides. This is especially dangerous for living organisms, soil and water, because, in combination with water vapor, these pollutants are the cause of acid rain. In addition, nitrogen oxides participate in the formation of ground-level ozone, which affects both human health and the condition of existing vegetation. Therefore, the distribution of air pollutants (NO_2, SO_2 and O_3) in the selected urban and rural areas, under the influence of power plants, located in the Lodz Voivodeship, in Poland, in Central-Eastern Europe, was analyzed for a 10-year period (2007–2016). As a result, it was possible to evaluate the impact of the entry into force of Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 "on ambient air quality and cleaner air for Europe" on the changes in emissions and concentrations of pollutants in selected locations. As a result of the analysis, a significant decrease in the concentration of SO_2 (by 75% in the urban area and by 59% in the rural area), and small changes (from - 8% to + 12%) in NO_2 and O_3 concentrations in ambient air were found. This indicates the effectiveness of actions aimed at reducing SO_2 emissions, however the influence of the power plants on the concentration of air pollutants in these areas is not clear. At the same time, considering the criterion of permissible concentration of ozone and nitrogen dioxide, although the air quality did not improve, the air quality index can be considered as being in the category of "good".

Key words
air pollution; rural area; urban area; power plants

Introduction

Production of heat and electricity for broadly understood "urban and village goals" is currently mainly based on large power stations. They can operate based on alternative/renewable sources or fossil fuels. As a result of fossil fuel combustion, significant amounts of pollutants, including gas pollutants, enter the environment [1]. And the presence of undesirable substances in the fuel, as well as the efficiency of air pollution control devices, determines, among others, the amount of nitrogen and sulfur oxides emitted into the atmosphere. Consequently, elevated concentrations of nitrogen and sulfur oxides in the air negatively affect human health and the environment [2–4]. This causes problems with the respiratory system (asthma) [2,5–6], the formation of acid rain [7] and reduced crop yield [8]. In addition, nitrogen oxides contribute to the formation of harmful to humans ground-level ozone [7,9]. Therefore, the emissions from point sources of power plants can be decisive in the total share of pollutant emissions in a given area, e.g. of a city, a voivodeship or a country [10].

Depending on the location and height of the emitter, air pollutants may enter areas with different terrain characteristics, population density and vegetation occurrence. Urban areas generally have high density of buildings, which is associated with a high population density and small vegetation area. Large share in air pollution have areal and linear sources, and air quality is often considered to be low there, negatively affecting human health [11–12] and therefore requiring improvement [13–14]. At the same time, significant amounts of air pollutants are emitted from industrial boiler plants and power stations, as well as combined heat and power plants, located in the city [15]. In agricultural areas, characterized by low density of buildings, low population density and large vegetation area, there is a lower concentration of pollutants from vehicle traffic and individual heating systems, which means that the quality of air in these areas is considered to be cleaner and therefore "better" [12,16]. However, the emission from point sources of power stations may have a major impact on the concentration of air pollutants in these areas [17–18].

As the importance of these issues and in order to protect human health and the environment, the European Parliament and the Council introduced Directive 2008/50/EC of 21 May 2008 "on ambient air quality and cleaner air for Europe" (the so-called CAFE Directive) [19]. Its detailed objective is, among others, taking actions aimed at identifying and reducing emissions of air pollution at source and establishing appropriate air quality objectives, taking into account, inter alia, World Human Organization recommendations and programs. According to the CAFE Directive [19], the "*air quality status should be maintained where it is already good, or improved* " and " *Member States should take action in order to comply with the limit values and critical levels, and where possible, to attain the target values and long-term objectives*". In addition to protecting human health, the Directive [19] focuses on the protection of vegetation and for this reason the assessment of air quality should be carried out not only in urban agglomerations (urban areas), where the concentration of pollutants often exceeds the target values, but also far from built-up areas, so on agricultural (rural) areas. In order to achieve the objectives of cleaner air for Europe, measures have been established to obtain and provide information as well as assess air quality and promote cooperation between European Union Member States in reducing air pollution.

In addition, due to the significant emission of air pollutants from large combustion plants, Directive of the European Parliament and of the Council 2010/75/EU of 24 November 2010 "on industrial emissions (integrated pollution prevention and control)"[20] was introduced, specifying the limits of industrial emissions (including emissions from power plants). The efforts to improve air quality were reflected in the legislation of the European Union Member States, and therefore in Poland the Environmental Protection Law [21] and related regulations [22] were amended, and national and local air protection programs were established [23].

In Poland, in order to identify, assess and plan the improvement of air quality, the air quality monitoring is carried out, inter alia by the Provincial Environmental Protection Inspectorates. Collection of data on air quality is carried out using measuring stations, both manual and automatic or mixed automatic-manual. As the criteria for air quality assessment, the values given by the WHO guidance [2,24] and by the Directive 2008/50/EC [19] are used as the recommended concentration of air pollutants, i.e. the maximum level of air pollution with no adverse effects on human health.

Since the impact on concentration of air pollutants in areas which vary in terms of urban planning, is made, among others, by point sources of combustion plants, e.g. local power plants and combined heat and power plants [23], therefore the following article analyzes the distribution of air pollutants in the selected urban and agricultural area in the Lodz Voivodeship, Poland, in the Central and Eastern Europe. As a result, the effect of emissions from point sources of large power stations on the concentration levels of selected pollutants in atmospheric air in a period of 10 consecutive years (2007–2016) was observed and analyzed.

Method description

The distribution of selected air pollutants has been analyzed based on data from measurement stations located: one in the city ("Lodz-Widzew") and the second in the agricultural/rural area ("Parzniewice"), in the Lodz Voivodeship, Poland, in Central and Eastern Europe, influenced by power plants in the last decade (years 2007–2016). The concentrations of NO_2, SO_2 and O_3 were analyzed, the measurements of which were carried out automatically in a continuous (hourly) mode at measurement stations that subject to the Provincial Environmental Protection Inspectorate in Lodz.

The measurement station "Lodz-Widzew" (fig. 1) is located at Czernika Street 1/3 in Lodz, in the urban area of low density residential (towards north, south and west) and the park (towards east) [25]. Lodz is a city with poviat rights, with a population of over 500,000 inhabitants and a population density of approximately 2390 people/km^2. The geographical coordinates of the position of the measuring station are N 51°45'28.98", E19°31'47.23". The measuring station is located approximately 1.4 km from the "EC-4" combined heat and power plant (with an electricity capacity about 198 MW and thermal power of approximately 820 MW, fueled with hard coal and biomass) and located at Andrzejewska Street 5 in Lodz (fig. 1). The “EC-4” power plant is one of two operating power plants in Lodz city and it belongs to the Veolia Energia Lodz SA (formerly Dalkia Lodz SA) company. The representativeness of the results of the “Lodz-Widzew” measurement station is several kilometers, which coincides with the number of about 10,000 inhabitants.

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Fig. 1. The "Lodz-Widzew" measuring station and "EC-4" power plant
Source: [26]

The "Lodz-Widzew" measuring station is equipped with $PM_{2.5}$, PM_{10}, NO, NO_2, SO_2, CO and O_3 analyzers (table 1).

Table 1. Equipment of "Lodz-Widzew" measuring station

Device type	**Air pollutant type**	**Measuring method**
BAM 1020	$PM_{2.5}$	attenuation of the beta ray; detection threshold <4.0 μg/m^3 (1 h)
Thermo 42i	NO, NO_2	chemiluminescent technology; detection threshold 50 ppb
Thermo 43i	SO_2	pulsed fluorescence technology; detection threshold 50 ppb
Thermo 48i	CO	absorbance of infrared radiation; detection threshold 1 ppm
Thermo 49i	O_3	UV photometric; detection threshold 0.5 ppb
Thermo 5014i	PM_{10}	attenuation of the beta ray; detection threshold <4.0 μg/m^3 (1 h)

Source: [25]

The "Parzniewice" measuring station is located in close proximity to Parzniewice village, in agricultural and rural area [27]. Parzniewice is a village with less than 500 inhabitants and is located in the Piotrkow Trybunalski poviat of population density of about 63 people/km^2. The geographical coordinates of the station's location are N 51°17'28.23", E19°31'03.20". The station is located about 13 km from the "PGE GIEK Bełchatow" power plant (with an electric power of approximately 5,342 MW, fuel: brown coal), located at Energetyczna Street 7, in Rogowiec near Belchatow city (fig. 2). The representativeness of the measurement station results is several kilometers [27].

Fig. 2. The "Parzniewice" measuring station and "PGE GIEK Belchatow" power plant
Source: [26]

The "Parzniewice" measuring station is equipped with NO, NO_2, SO_2, and O_3 analyzers (table 2).

Table 1. Equipment of "Parzniewice" measuring station

Device type	Air pollutant type	Measuring method
Thermo 42i	NO, NO_2	chemiluminescent technology; detection threshold 50 ppb
Thermo 43i	SO_2	pulsed fluorescence technology; detection threshold 50 ppb
Thermo 49i	O_3	UV photometric; detection threshold 0.5 ppb

Source: [27]

Additionally, for the analysis of emissions and concentrations of air pollutants, the Provincial Environmental Protection Inspectorate reports of the annual air quality assessment in the Lodz Region [23] from 2007 – 2017 were used.

Results

After analyzing the ten-year data, it can be noticed that the concentration of NO_2 is characterized by a slight change of values for the "Lodz-Widzew" and a slight decrease at the "Parzniewice" measurement station. The average annual NO_2 concentration ranged from 16.4 to 19.1 µg/m^3 (average 18.3 µg/m^3) in the first location, and from 12.1 to 15.1 µg/m^3 (average 13.4 µg/m^3) in the second location, which is significantly below the recommended by WHO average annual value of 40 µg/m^3 (due to human health protection) and 30 µg/m^3 (due to vegetation protection) [2]. In the case of the "Lodz-Widzew" measuring station, hourly average NO_2 concentrations exceeded 40 µg/m^3 for 548 hours per year and were no more than 139 µg/m^3. However, at the "Parzniewice" they exceeded 40 µg/m^3 for 340 hours per year and were no more than 108.9 µg/m^3. In summary, in both cases, within 10 years, NO_2 concentrations did not exceed the recommended average hourly value of 200 µg/m^3 (fig 3).

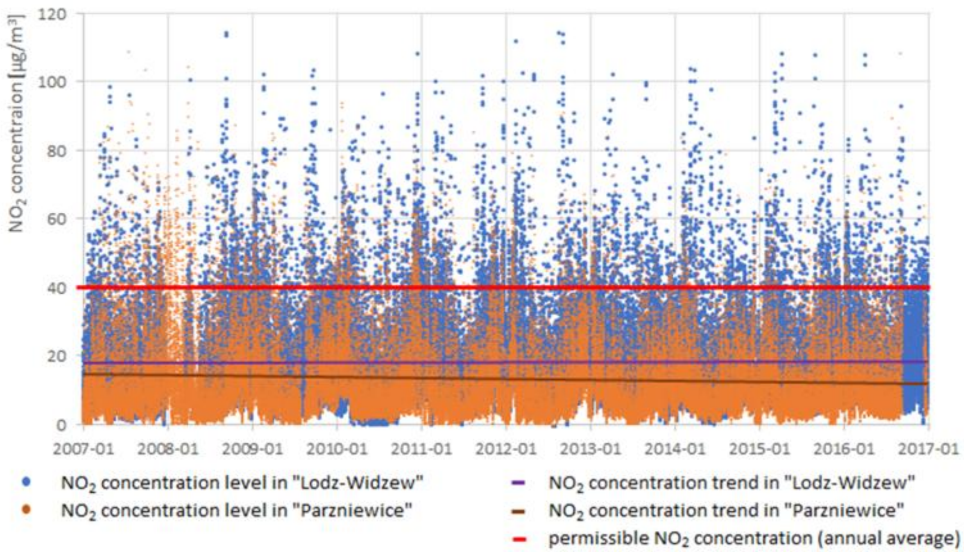


Fig. 3. NO_2 concentrations in the selected locations in 2007–2016

Source: Author's

The annual average concentration of SO_2 in the air decreased markedly and ranged from 4.0 to 15.8 µg/m^3 (average 9.9 µg/m^3) in the city, and from 4.0 to 11.5 µg/m^3 (average 8.6 µg/m^3) in the rural area. Therefore, the SO_2 concentrations were significantly below the WHO recommended annual average of 50 µg/m^3 (due to human health protection) and 30 µg/m^3 (due to vegetation protection). However, it was observed that the winter season criterion of plant protection (from 1 October to 31 March) of 20 µg/m^3 according to the

Regulation [28], was exceeded in winter 2007/2008 in the urban area. What is more, in the case of the "Lodz-Widzew", the average hourly SO_2 concentrations exceeded 50 μg/m^3 for around 63 hours per year and were no more than 230.4 μg/m^3. And at the "Parzniewice" measuring station, SO_2 concentrations exceeded 50 μg/m^3 for around 64 hours a year and were no more than 164.6 μg/m^3. However, within 10 years of measuring the concentration of SO_2, there was no exceedance of the recommended average daily value of 125 μg/m^3 (fig. 4).

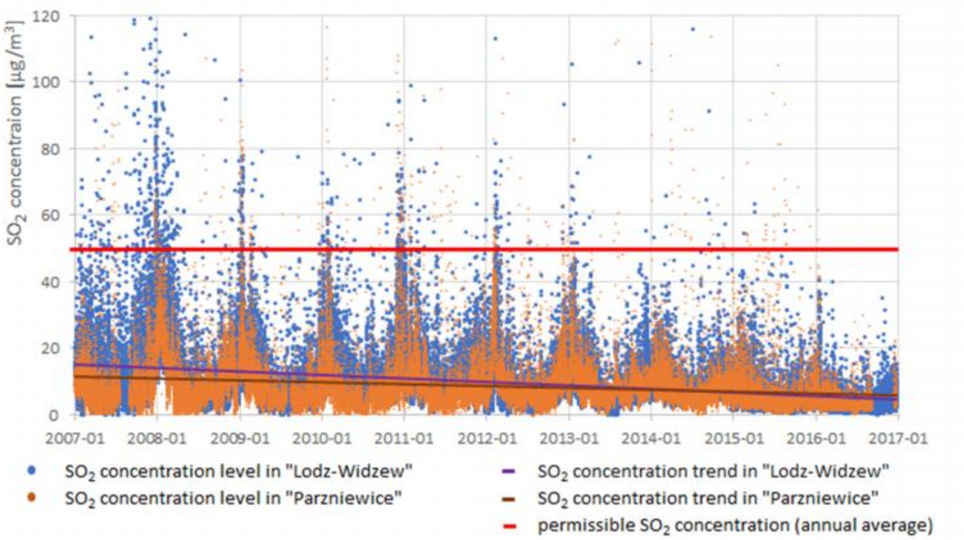


Fig. 4. SO_2 concentrations in the selected locations in 2007–2016
Source: Author's

As to the ground-level ozone, the O_3 average annual concentration in air changed slightly and ranged from 51.1 to 54.7 μg/m^3 (average 52.8 μg/m^3) in the city, and from 51.6 to 59.8 μg/m^3 (average 55.8 μg/m^3) in the village. In the case of the "Lodz-Widzew" measuring station, the hourly average O_3 concentrations exceeded 120 μg/m^3 on average for 202 hours per year and were no more than 179.1 μg/m^3. However, at the "Parzniewice" measuring station, they exceeded 120 μg/m^3 on average for around 225 hours per year and were no more than 184.7 μg/m^3 (fig. 5). Also, within 10 years of the O_3 concentration measurement, the recommended O_3 concentration of 120 μg/m^3 of 8-hour average was exceeded. In the urban area (represented by the "Lodz-Widzew" station) it was about 17 exceedances per year, and in the agricultural area (represented by the "Parzniewice" station) about 19. The least number of exceedances occurred in 2009 (8 and 16 respectively), and the highest number of exceedances occurred in 2015 (31 and 30 respectively).

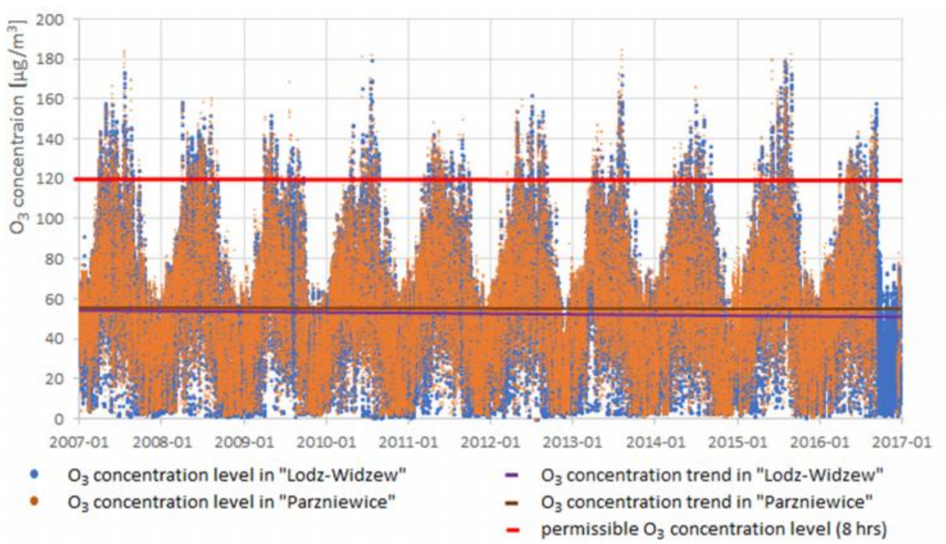


Fig. 5. O_3 concentrations in the selected locations in 2007–2016
Source: Author's

In addition, changes in the concentrations of pollutants in the air were compared with the equivalent emission of Veolia Energia Lodz SA (formerly Dalkia Lodz SA), to which belongs two operating power plants (including "EC-4" power plant) in Lodz city, and with the equivalent emission of PGE GIEK Bełchatow power plant. The decrease in the equivalent emission from power plants was mainly related to the capture of sulfur dioxide. Although in 2016 the 76% emission reduction by Veolia Energia Lodz SA corresponds to the 75% reduction of SO_2 concentration at the "Lodz-Widzew" measuring station, and similarly the 61% emission reduction by PGE GIEK Bełchatow corresponds to the 59% reduction of SO_2 concentration at the "Parzniewice" measuring station, in the analyzed period of 10 years there was no clear correlation between the reduction of equivalent emissions from power plants and changes in the concentration of SO_2 and NO_2 (table 3, table 4).

Table 3. Changes in the emissions and concentration of air pollutants at "Lodz-Widzew" in 2007–2016

Year	**Lodz-Widzew**								**Veolia Energia Lodz SA**	
	Concentration [μg/m^3]				**Change from 2007 [%]**				**Equivalent emission [Mg/yr]**	**Change from 2007 [%]**
	NO_2	**NO**	**SO_2**	**O_3**	**NO_2**	**NO**	**SO_2**	**O_3**		
2007	16.4	3.2	15.8	54.7	-	-	-	-	18305.1	-
2008	19.1	3.3	12.2	53.2	17%	4%	-23%	-3%	12822.4	-30%
2009	19.0	5.0	9.4	50.7	16%	57%	-41%	-7%	11890.7	-35%
2010	18.1	4.2	12.9	52.2	10%	33%	-18%	-5%	13061.5	-29%
2011	19.4	4.1	11.6	53.7	18%	29%	-26%	-2%	11236.6	-39%
2012	19.1	3.7	9.5	52.3	16%	15%	-40%	-4%	9952.5	-46%
2013	18.6	3.9	9.3	53.1	13%	24%	-41%	-3%	8302.5	-55%
2014	16.9	3.8	9.0	51.2	3%	19%	-43%	-6%	5302.1	-71%
2015	18.5	3.3	5.3	55.6	13%	5%	-67%	2%	6518.0	-64%
2016	18.3	3.4	4.0	51.1	12%	8%	-75%	-7%	4439.9	-76%

Source: Author's

Table 4. Changes in the emissions and concentration of air pollutants at "Parzniewice" in 2007–2016

Year	**Parzniewice**								**PGE GIEK Bełchatow**	
	Concentration [μg/m^3]				**Change from 2007 [%]**				**Equivalent emission [Mg/yr]**	**Change from 2007 [%]**
	NO_2	**NO**	**SO_2**	**O_3**	**NO_2**	**NO**	**SO_2**	**O_3**		
2007	14.3	2.4	9.8	57.3	-	-	-	-	114968.4	-
2008	14.4	2.7	11.5	55.1	0%	14%	17%	-4%	83623.3	-27%
2009	14.1	2.8	8.9	52.8	-2%	15%	-9%	-8%	73230.9	-36%
2010	15.1	2.7	9.0	53.7	6%	12%	-8%	-6%	95304.4	-17%
2011	12.6	2.5	9.1	56.3	-12%	2%	-7%	-2%	100452.0	-13%
2012	12.9	2.3	10.0	56.5	-10%	-4%	2%	-1%	98761.6	-14%
2013	12.5	2.0	9.1	56.6	-13%	-17%	-7%	-1%	81780.8	-29%
2014	12.5	2.1	8.3	51.6	-13%	-15%	-15%	-10%	91315.6	-21%
2015	12.1	1.9	6.1	58.2	-16%	-21%	-38%	2%	92684.0	-19%
2016	13.2	1.7	4.0	59.8	-8%	-29%	-59%	4%	44547.4	-61%

Source: Author's

For the comparison, changes in wind directions at analyzed points were calculated. Meteorological conditions were measured at “Lodz-Widzew”, and at measuring station “Piotrkow Trybunalski”, which is the nearest (around 19 km) measuring station to “Parzniewice”. The “EC-4” power plant is located at SE direction to “”Lodz-Widzew”, and “PGE GIEK Belchatow” is located at WSW direction to “Parzniewice”. However, at “Lodz-Widzew” dominated (13.4%) wind direction W, and near to “Parzniewice”, at “Piotrkow” measuring station, dominated (9.3%) wind direction SW (fig. 6). Also, wind direction changed from year to year (table 5), which surely influenced concentration of air pollutants.

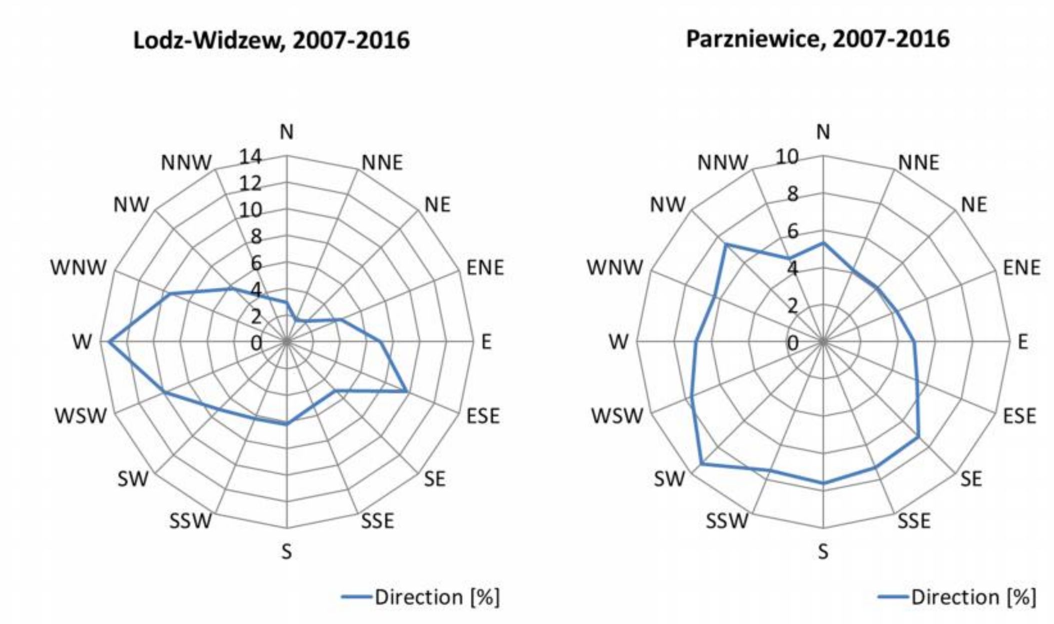


Fig. 6. Wind directions at “Lodz-Widzew” and near “Parzniewice” measuring stations in 2007-2016
Source: Author’s

Table 5. Changes in the wind direction

Year	Wind direction [%]			
	Lodz-Widzew		Parzniewice	
	SE	Change from 2007	WSW	Change from 2007
2007	3.8	-	10.5	-
2008	4.6	+ 0.8	15.8	+ 5.3
2009	5.7	+ 1.8	11.1	+ 0.6
2010	4.6	+ 0.8	4.2	- 6.3
2011	5.2	+ 1.4	12.1	+ 1.7
2012	5.2	+ 1.4	4.6	- 5.8
2013	4.3	+ 0.4	4.2	- 6.3
2014	8.0	+ 4.2	2.5	- 7.9
2015	4.1	+ 0.3	5.7	- 4.7
2016	6.2	+ 2.4	5.7	- 4.7

Source: Author’s

The relationships between the NO_2 and SO_2 concentrations at the "Lodz-Widzew" and "Parzniewice" measurement stations, and the respective power plants are shown in fig. 7 and fig 8.

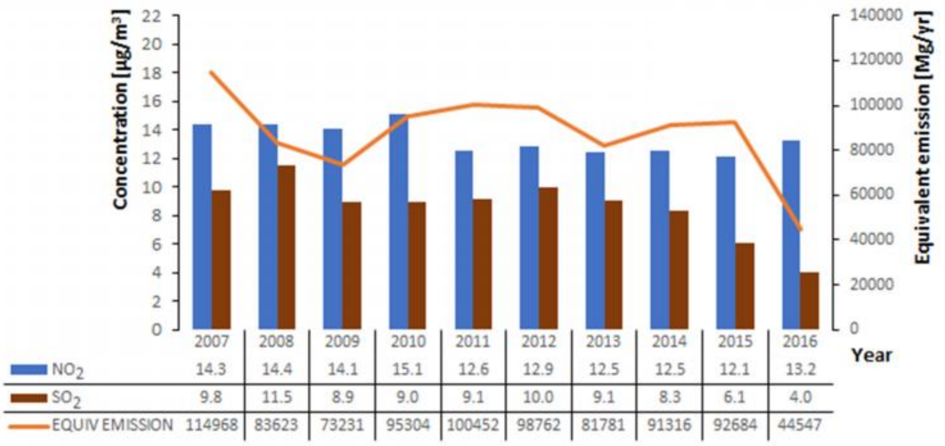


Fig. 7. Air pollutants concentrations at the "Lodz-Widzew" and equivalent emission of Veolia Energia Lodz
Source: Author's

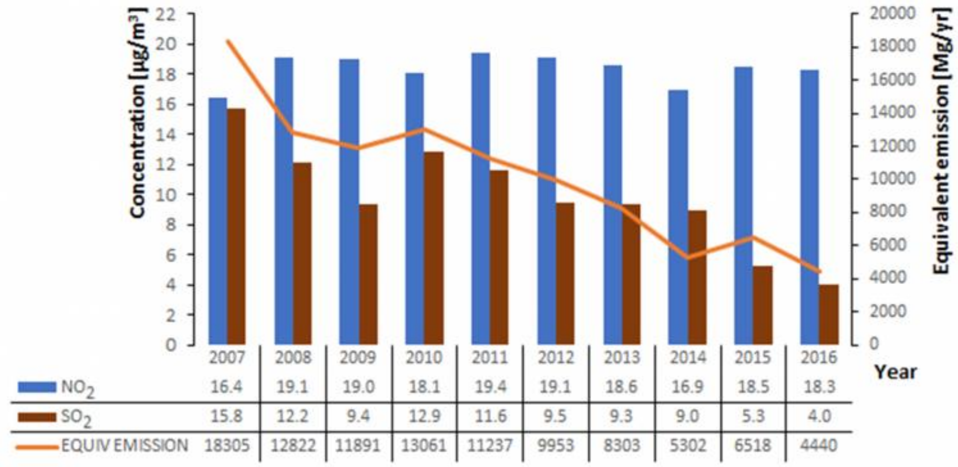


Fig. 8. Air pollutants concentrations at the "Parzniewice" and equivalent emission of PGE GIEK Belchatow
Source: Author's

Analyzing the population density in poviats, in which measurement stations are located, i.e. indirectly also the number of people exposed to adverse air pollution, no dependence between NO_2, SO_2 and O_3 concentration and the number of people in the analyzed areas was observed. The city of Lodz, which is a town poviat, where high and low density residential, industrial and service zones predominate, and where the "Lodz-Widzew" measuring station is located, is characterized by a large but decreasing value of population density (about 0.9% per year), Meanwhile, for 10 years the NO_2 concentration increased by 12%, and the O_3 concentration decreased by 7% (fig. 9)

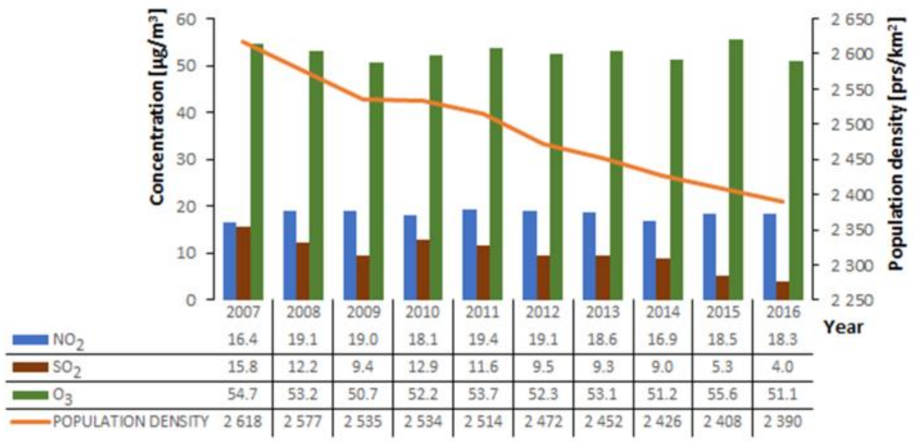
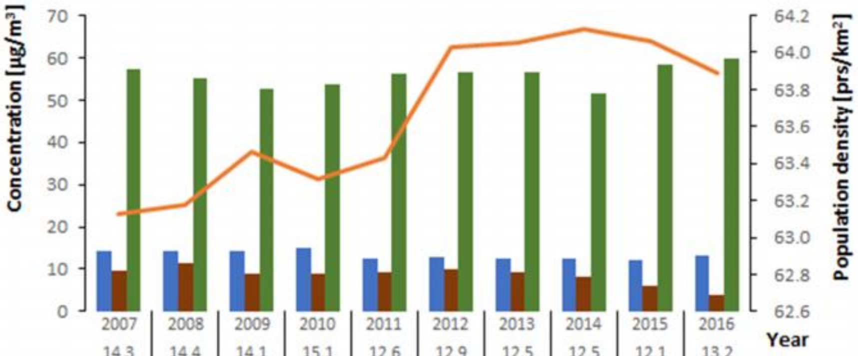


Fig. 9. Air pollutants concentrations at the "Lodz-Widzew" and the population density of Lodz city
Source: Author's

The Piotrkow poviat in which rural and agricultural areas predominate, and where the "Parzniewice" measuring station is located, is characterized by a small but increasing value of population density (about 0.1% per year), while in 10 years the NO_2 concentration decreased by 8%, and O_3 concentration increased by 4% (fig 10).



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
NO_2	14.3	14.4	14.1	15.1	12.6	12.9	12.5	12.5	12.1	13.2
SO_2	9.8	11.5	8.9	9.0	9.1	10.0	9.1	8.3	6.1	4.0
O_3	57.3	55.1	52.8	53.7	56.3	56.5	56.6	51.6	58.2	59.8
POPULATION DENSITY	63.1	63.2	63.5	63.3	63.4	64.0	64.1	64.1	64.1	63.9

Fig. 10. Air pollutants concentrations at the "Parzniewice" and the population density of Piotrkow poviat
Source: Author's

Conclusions

As a result of the analysis carried out in selected locations over a period of 10 years (between 2007 and 2016), small changes (between -8% and +12%) of NO_2 and O_3 were found in urban and agricultural areas. However, when comparing emissions from local power plants and combined heat and power plants with the concentration of pollutants in selected metering stations, no clear correlation was found between the reduction of equivalent emissions from power plants and changes in the SO_2 and NO_2 concentration in the air. On the other hand, change in wind directions during 2007-2016 period could influenced concentration of air pollutants. Especially that "Lodz-Widzew" measuring station was not located in the dominant wind direction from "EC-4" power plant. The 10-year distribution of pollutant concentration was different for both locations. The levels of air pollutants in urban and rural areas differed by approximately ±13–35% for NO_2, and ±16– 38% for SO_2, and ±5–17% for O_3. The concentrations of NO_2 and SO_2 in the air were higher in urban areas by 13–35% and 0–38% respectively. However, it was observed that in 2012 and 2015 the SO_2 concentration in the agricultural area was higher by 6% and 16% respectively. In contrast, the NO_2 and SO_2 concentration limit values were not exceeded for both urban and agricultural locations, except for the winter of 2007/2008 at the "Lodz-Widzew" station, where the average SO_2 concentration exceeded 20 $\mu g/m^3$, which is a criterion for plant protection. This means that, considering the protection of human health, air quality was generally good in the analyzed period in both selected locations. In addition, NO_2 and SO_2 concentrations at the selected urban and rural locations did not differ significantly.

On the other hand, the concentration of O_3 was always higher (by 1–17%) in the agricultural area, although there was a lower concentration of NO_2 (which contributes to the formation of tropospheric ozone). And the occurrence of ground-level ozone is a disadvantage for the economy of the agricultural area due to the negative impact on plant vegetation, especially since the exceedance of the recommended concentration of O_3 in the air occurred mostly from April to August, i.e. in the summer. It should be remembered that ground-level ozone is formed as a result of photochemical transformation of the oxidation of nitrogen oxides in the presence of CO, CH_4 and non-methane volatile organic compounds (NMVOCs). Therefore, the main sources of ozone pollution are energy, transport (NO_x), industry (NMVOCs), communal housing (CO), mining industry, fuel distribution, agriculture and landfills (CH_4). Therefore, it is necessary to take a closer look at the processes of ground-level ozone formation in agricultural areas, especially in relation to the concentration of nitrogen oxides, as well as the impact of sources of air pollutants other than power stations [29]. For this reason, it seems that the next step in the protection of vegetation should be the analysis of the location of pollution sources in relation to agricultural and forest areas. At the same time, according to Guereirro et al. [30], differences in O_3 concentration in urban and agricultural areas result from the removal of ozone from the atmosphere by NO and thus from the formation of NO_2, which seems to be in line with the results of this analysis. However, according to this assumption, the NO_2 concentration should increase with decreasing NO and O_3 concentrations. However, in the agricultural area NO_2 decreased by 8% and NO by 29% (with NO/NO_2 ratio decrease by 23%), while the O_3 concentration increased by 4%. And in the city, the NO_2 concentration increased by 12%, and NO by 8% (with NO/NO_2 ratio decrease by 3%), while the O_3 concentration decreased by 7%.

In the analysis no relationship was observed between changes in NO_2, SO_2 and O_3 concentrations in the air, and the average density of population in the surrounding areas, both in the city and in the countryside. Hypothetically, the change in the number of inhabitants living in a given area should change the emission associated to vehicles (linear sources of emission) and residential boilers (area sources of emission) or the trend of emission of pollutants [31–32], but this analysis has not shown it. Recognized lack of correlation between the growth and fall of population density and the concentration of pollutants indirectly indicates the high importance of emission from point sources in the average concentration of pollutants in selected areas.

Tightening the air protection criteria, inter alia as a result of the implementation of EU Directives [19-20], allowed to significantly reduce the emission of SO_2 air pollution from point sources of the power industry, which resulted in a drop in the concentration of this pollutant in the air in selected urban and agricultural areas. The analyzed power plants reduced emission by 61-76% in last 10 years. Still, the cost of modernization of Polish power plants is estimated to around 3 billion USD [33]. Also, the PGE power producer is planning to spend up to around 470 million USD on emission reduction in line with European Union regulations [33]. If a current trend in power plant emission reduction will sustain, there can be another decrease of 60-80% of equivalent emission in further 10 years.

As to the current situation, the threat to urban and rural population and the threat to vegetation, caused by the presence of SO_2 in the air, and the possibility of acid rainfall, decreased. However, taking into account the criterion of permissible concentration of ground-level ozone and nitrogen dioxide, it can be concluded that the air quality index can usually be considered as "good". Unfortunately, during the whole decade, the levels of concentrations of these harmful gases in the air have not significantly improved, which in combination with exceedances of O_3 concentrations limit values in subsequent years may expose the vegetation during the growing season and people living in these areas to harmful effects of NO_2 and O_3.

References

[1] M. L. Williams, 6 – Patterns of Air Pollution in Developed Countries, Air Pollution and Health (1999) 83–104 https://doi.org/10.1016/B978-012352335-8/50081-8

[2] WHO, 2000. Air Quality Guidelines for Europe, World Health Organization, Regional Office for Europe, WHO Regional Publications, European Series, No. 91, Copenhagen, 2000

[3] R. Cichowicz, G. Wielgosiński, W. Fetter, Dispersion of atmospheric air pollution in summer and winter season, Environmental Monitoring and Assessment, (2017) 189–605 https://doi.org/10.1007/s10661-017-6319-2

[4] WHO, 2013. Review of Evidence on Health Aspects of Air Pollution - REVIHAAP Project. Technical Report, World Health Organization, Regional Office for Europe, Copenhagen, 2000.

[5] U. Ackermann-Liebrich, R. Rapp, 25 – Epidemiological Effects of Oxides of Nitrogen, Especially NO2, Air Pollution and Health (1999) 561–584, https://doi.org/10.1016/B978-012352335-8/50100-9

[6] R. B. Schlesinger, 26 – Toxicology of Sulfur Oxides, Air Pollution and Health 1999, Pages 585–602, https://doi.org/10.1016/B978-012352335-8/50101-0

[7] S. Sudalma,P. Purwantoa,L. W. Santosod, The Effect of SO2 and NO2 from Transportation and Stationary Emissions Sources to SO42− and NO3− in Rain Water in Semarang, Procedia Environmental Sciences Volume (23) (2015) 247–252 https://doi.org/10.1016/j.proenv.2015.01.037

[8] R. Mmuzika, R. Pguyette, T. Zielonka, A. Mliebhold, The influence of O3, NO2 and SO2 on growth of Picea abies and Fagus sylvatica in the Carpathian Mountains, Environmental Pollution 130 (1) (2004) 65–71 https://doi.org/10.1016/j.envpol.2003.10.021

[9] G. D. Thurston, K. Ito, 22 – Epidemiological Studies of Ozone Exposure Effects, Air Pollution and Health (1999) 485–510 https://doi.org/10.1016/B978-012352335-8/50097-1

[10] Environmental Protection Inspection, National Mosaic Report. State of the Environment in the years 2000-2007 (Inspekcja Ochrony Środowiska, Krajowy Raport Mozaikowy. Stan Środowiska w latach 200-2007), Library of Environmental Monitoring, Warsaw 2010 http://www.gios.gov.pl/stansrodowiska/upload/file/pdf/download/krajowy_raport_mozaik_n.pdf

[11] K.N. Priftis, M. B. Anthracopoulos, A. G. Paliatsos, G. Tzavelas, A. Nikolaou-Papanagiotou, P. Douridas, P.Nicolaidou, E. Mantzouranis, Different effects of urban and rural environments in the respiratory status of Greek schoolchildren, Respiratory Medicine 101 (1) (2007) 98–106 https://doi.org/10.1016/j.rmed.2006.04.008

[12] H. Strosnider, C. Kennedy, M. Monti, F. Yip, Rural and Urban Differences in Air Quality, 2008-2012, and Community Drinking Water Quality, 2010-2015 - United States, Surveillance Summaries 66 (13) (2017) 1-10 http://dx.doi.org/10.15585/mmwr.ss6613a1

[13] S. Gulia, S.M. S. Nagendra, M. Khare, I. Khanna, Urban air quality management–A review, Atmospheric Pollution Research 6 (2) (2015) 286–304 https://doi.org/10.5094/APR.2015.033

[14] G. Wielgosiński, J. Czerwińska, O. Namiecińska, R. Cichowicz, Smog episodes in the Lodz agglomeration in the years 2014-17, E3S Web of Conferences 28 (01039) (2018) https://doi.org/10.1051/e3sconf/20182801039

[15] C. Holman, 8 – Sources of Air Pollution, Air Pollution and Health (1999) 115–148 https://doi.org/10.1016/B978-012352335-8/50083-1

[16] D. M. Whitacre, Reviews of Environmental Contamination and Toxicology, Springer Science+Business Media, New York 2013

[17] R. Cichowicz, G. Wielgosiński, W. Fetter, Impact of pollutants emitted by large industrial plants on the quality of atmospheric air, Polish Journal of Environmental Studies 26 (5A) (2017) 8-13

[18] R. Cichowicz, Spatial distribution of pollutants in the area of the former CHP plant, E3S Web of Conferences 28 (01007) 2018 https://doi.org/10.1051/e3sconf/20182801007.

[19] EU, 2008. Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on Ambient Air Quality and Cleaner Air for Europe, OJ L 152, 11.6.2008, pp. 1–44.

[20] EU, 2010. Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) OJ L 334, 17.12.2010, p. 17–119

[21] PL, 2001. The Act Of 27 April 2001, The Environmental Protection Law (Ustawa z dnia 27 kwietnia 2001 r. Prawo ochrony środowiska), Dz.U. 2001 nr 62 poz. 627

[22] PL, 2012. Regulation of the Minister of the Environment of 11 September 2012 on air protection programs and short-term action plans (Rozporządzenie Ministra Środowiska z dnia 11 września 2012 r. w sprawie programów ochrony powietrza oraz planów działań krótkoterminowych), Dz.U. 2012 poz. 1028.

[23] http://www.wios.lodz.pl/Roczne__oceny_jakosci_powietrza,141

[24] WHO, 2006. Air Quality Guidelines. Global Update 2005. Particulate Matter, Ozone, Nitrogen dioxide and Sulfur dioxide. World Health Organization, Regional Office for Europe, Copenhagen, 2005.

[25] http://www.wios.lodz.pl/Lodz-Widzew,211,2

[26] https://www.google.pl/maps

[27] http://www.wios.lodz.pl/Parzniewice,211,6

[28] PL, 2012. Regulation of the Minister of the Environment of 24 August 2012 on the levels of certain substances in the air (Rozporządzenie Ministra Środowiska z dnia 24 sierpnia 2012 r. w sprawie poziomów niektórych substancji w powietrzu), Dz.U. 2012 poz. 1031

[29] R. C. Wilson, Z. L. Fleming, P. S. Monks, G. Clain, S. Henne, I. B. Konovalov, S. Szopa, L. Menut, Have primary emission reduction measures reduced ozone across Europe? An analysis of European rural background ozone trends 1996-2005, Atmos. Chem. Phys. 12 (2012) 437–454 http://dx.doi.org/10.5194/acp-12-437-2012

[30] C. B.B. Guerreiro, V. Foltescu, F. de Leeuw, Air quality status and trends in Europe, Atmospheric Environment 98 (2014) 376–384 http://dx.doi.org/10.1016/j.atmosenv.2014.09.017

[31] H. Shen, Y. Chena, A. G. Russell, Y. Hu, G. Shen, H. Yu, L. R.F. Henneman, M. Rua, Ye Huang, Q. Zhong, Y. Chen, Y. Li, Y. Zou, Impacts of rural worker migration on ambient air quality and health in China: From the perspective of upgrading residential energy consumption, Environment International (2018) https://doi.org/10.1016/j.envint.2017.11.033

[32] S.P. Bhoyar, S. Dusad, R. Shrivastava, S. Sidharth Mishra, N. Gupta, A. B. Rao, Understanding the impact of lifestyle on individual carbonfootprint, Procedia - Social and Behavioral Sciences 133 (2014) 47 – 60 https://doi: 10.1016/j.sbspro.2014.04.168

[33] https://www.reuters.com/article/us-pge-polska-investment-idUSKCN10L12Q

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CHANGE OF THE COMMUNICATION SERVICE MODEL ON THE EXAMPLE OF THE HOUSING FROM THE 2ND HALF OF THE 20TH CENTURY "POD DALNIĄ" IN KIELCE

Abstract
For years, the motorized and uncontrolled degradation of the public space of housing estates from the second half of the twentieth century in Poland has been appropriated. This has a negative impact on their functioning and image. The aim of the work is a detailed analysis of Kielce housing estate from the second half of the last century – Pod Dalnią, mainly in the spatial and communication aspect. The main focus was on the study of changes in the communication service model and the diagnosis of the parking problem, which also generates other tensions in the housing estate. This strives to formulate guidelines for comprehensive changes and strategies for the development of a housing estate that is not adapted to contemporary requirements and needs.

Key words
block settlements, revitalization, urban units, housing estate, transport services, parking lots.

Introduction

This study presents the results of the analysis of the parking problem in one of the housing estates from the second half of the last century in Kielce – "Pod Dalnią" housing estate. The work is part of the research conducted for the needs of the dissertation concerning the change in the model of communication service for Kielce housing estates from the second half of the twentieth century in the context of their revitalization. This is a significant issue in the era of appropriation by the motorized housing estate and reduction of its usability. Especially, nowadays in Polish cities the number of cars is growing faster than the number of inhabitants. Cars – one of the most valuable material assets that stand almost 96% of the time unused [1], force you to create additional space to store them. Space that is a valuable and scarce good and an important element in shaping the image of modern society, because it is supposed to be an area of social interaction, and seems to still not be.

The scope of research to diagnose Polish block settlements in the spatial and communication aspect as well as monitoring of changes taking place on them is small. This does not allow for the creation of a comprehensive recovery program that would inhibit degradation processes and prevent negative phenomena resulting from rapid civilizational changes. Due to the complexity of the subject being studied, it is necessary to use various research tools. In order to verify the authenticity and authenticity of the results of the research, the author undertook the so-called their triangulation, or confronting expert and participatory studies [2]. As part of the research of the "Pod Dalnią" housing estate, the following were carried out:

- analysis of literature dealing with housing estates from the second half of the twentieth century: their changes over the years, problems, revitalization, transport services, etc.,
- review of planning and strategic documents of the city of Kielce,
- analysis of the target development plan of the housing estate from the second half of the twentieth century,
- study of changes and development of the housing estate based on photomaps from various years,
- vision of the area with the collection of photographic documentation,
- urban inventory of the estate,
- observations and interviews with residents and employees of housing cooperatives,
- analysis of needs, problems and space changes based on the tasks reported and implemented from the Civil Budget.

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It is also planned to conduct a survey in designated spatial units, the results of which will be confronted with the analyzes carried out. The author undertook to develop studies of a theoretical and empirical nature, bearing in mind also the future application dimension of research results. She strives to determine the possibilities of transformations and development directions of the Kielce housing estate in the context of changes in the model of its communication service and implementation of the goals set in the "Transport plan for the city of Kielce..." [3], where it is recommended in the field of parking policy to create parking measurements and surveys with parking users.

Spatial changes of housing estates from the second half of the 20th century

Own research in Kielce and carried out in other Polish cities [4, 5, 6, 7] indicate that since the beginning of the systemic transformation, i.e. for almost 30 years, block settlements have been subject to intense uncontrolled changes in many dimensions. Even at the stage of implementing the development plans, they were deprived of essential elements, although in the majority they were planned as comprehensive, comprehensive housing complexes based on favorable norms regarding building orientation, insolation, communication, accessibility of services, public spaces and green areas. However, in the course of implementation, the focus was primarily on housing, in order to quickly satisfy the post-war "housing hunger". Many good, unconventional housing estates have become a boring mono-functional space [8]. By not realizing public utilities and public spaces associated with them, the layout of pedestrian routes began to develop quite chaotically. In this way, the spaces lost their uniqueness, character and functional and spatial diversity. Urban interiors became indefinite, deprived of life, implementing emotionally non-emotionally demanding needs.

Intensive development of individual transport has also contributed to this fact. In spite of appearing in the 1970s, the premises pointing to the increase in the number of cars, and postulates regarding the increase of the parking ratio to 1: 1 (one parking space per apartment) [9] no action was taken. Estates from the second half of the last century were designed according to contemporary standards – 1 parking space for several apartments. Currently, the demand for the number of parking spaces in residential housing units is at least 1 space per flat[1]. Over the years, we have managed to get accustomed to the appropriation and degradation of housing estate by motorists, hence there is a social acceptance of the current principle of subordinating everything to parking needs, with progressive damage to our health and the quality of the housing environment. Parking has become a kind of social practice that causes tensions in neighborly relations, affects the limitation of social contacts and the appearance of space, which is a very important element of this practice.

In addition to spontaneous activities caused by changes in civilization and technological development, we can also distinguish targeted activities aimed at improving the image and improving living conditions in the settlements from the second half of the last century. They are usually taken by entities responsible for housing estates, mainly housing co-operatives, communities, municipal authorities and increasingly non-governmental organizations. Their activities are usually limited to technical modernization and improvement of the quality of buildings and public space, carried out in a punctual manner and insufficiently focused problematically and territorially [10]. The problem is also the lack of linking infrastructural projects with social and economic projects and the preparation of projects without a comprehensive diagnosis of the situation of a given area and defining detailed objectives of the planned activities [11]. Another difficulty is the diversified ownership structure of the housing estates, as it requires very good communication and cooperation between the entities managing the housing estates.

Research in the Kielce housing estate "Pod Dalnią"

The "Pod Dalnią" housing estate is one of the many estates built in the second half of the 20th century in Kielce - a post-socialist city with less than 190,000 inhabitants (as of May 18, 2018 according to population records). The city developed in a large part urban and social after the Second World War in the years 1950-1990. The text of the Local Revitalization Program of urban, post-industrial and post-military areas in the city of Kielce for

[1] The required number of parking spaces is determined in the local spatial development plan, or in the decision on land development and development conditions. Such a minimum indicator was also defined in the draft "National Urban Regulations" of August 17, 2010.

2014-2020 [12] draws attention to the importance of multi-family housing estates built in the second half of the last century, development of the commune and their individual high development potentials. In housing complexes from the second half of the 20th century, still live 1/3 of citizens of Kielce. Due to the lack of comprehensive research and modernization activities undertaken over the years, Kielce housing estate faces many problems and threats related to the ongoing technical and social degradation. The results of the questionnaire, commissioned by the Kielce city authorities [13], show that the greatest negative impact on the comfort of living in "blocks of flats" has too few parking spaces, nuisance related to traffic and improper parking cars and too little decorated park and garden areas. However, in the "Transport Plan for the City of Kielce ..." [3] parking policy is listed as one of the main elements of sustainable city mobility management with a developed offer of public transport, bicycle and pedestrian traffic, integration of spatial planning with transport planning and educational and promotional activities. The transport plan also assumes a reduction in the share of car journeys and the value of the number of vehicles per household (one flat) to 0.75. In addition, attention is paid to the creation of functionally diverse spatial units, with good access to public transport, an extensive bicycle system and high quality of local housing areas available on foot. This justifies the need to monitor the parking situation on the housing estates, to restore the balance between pedestrian, bicycle and vehicular traffic and to invest in an attractive, functionally diverse space adapted to the needs of residents, and not only for cars.

The main purpose of the research carried out by the author in the Kielce housing estate "Pod Dalnią", created in the second half of the twentieth century, is to diagnose its condition mainly in the spatial and communication aspect and to show the changes that have taken place in its structure for years. The main focus was on the change of the communication service model and the parking problem, which generates other problems in space. The housing estate according to the diagnosis from the Local Revitalization Program[2] is one of the least degraded housing assumptions in Kielce, "with a relatively very good situation" [12], nevertheless has similar problems, contributing to the degradation of space, like other Kielce settlements. A thorough diagnosis of the condition and monitoring of housing developments is necessary to develop a comprehensive strategy for the transformation and development of the housing estate. It is assumed that such a strategy would help to curb the spatial and social degradation process and protect against negative phenomena and threats that occur in other settlements with a higher degree of degradation in Kielce.

"Pod Dalnią" housing estate is located in the western part of Kielce, at the feet of Karczówka, between the Czarnów, Ślichowice and Gwarków settlements (Fig. 1). Its border from the east is marked by Adama Naruszewicza street and a single-family housing estate, Piekoszowska street from the south, and Grunwaldzka main street from the west. From the north-west, the estate borders the avenue of Jerzego Szajnowicza-Iwanowa with a much larger housing estate, Ślichowice, which is managed by the same housing cooperative "Domator", hence it is often perceived as part of a large complex of the Ślichowice estate. Despite the rather peripheral location, it is well connected with the rest of the city. It is 4.7 km away from Kielce market, which takes about about 15 minutes by car or public transport (18 daily bus lines and 1 night bus).

[2] The diagnosis of settlements in the Local Regeneration Program of urban, post-industrial and post-military areas in the city of Kielce for the years 2014-2020 was carried out according to 10 partial indicators (9 indicators of quantitative analysis and one indicator of qualitative analysis).

Fig. 1. Location of the "Pod Dalnią" housing estate on the map of Kielce.
Source: Author's.

The housing estate is a complex of blocks of flats built in the second half of the 1980s with the so-called "Big plate", in W-70 MK[3] technology. On the eastern side of the estate, along Naruszewicza street there are also several single-family houses. The big-plate building consists of 24 residential buildings, which were built in a short period of time, from August 1988 to September 1989[4]. They were designed by the Investment Design and Services Department "INWESTPROJEKT". The final implementation plan for the "Pod Dalnią" housing estate dates from 1985 and presents a comprehensive solution to the entire foundation with an extensive communication service system and a road system that facilitates contact with educational buildings and other service buildings (Fig. 2).

[3] The open system of the big plate used in Poland, developed in 1973.
[4] Date of commissioning of the first and last building. Source: Information obtained at the "Domator" Housing Cooperative.

Fig. 2. Implementation plan for the "Pod Dalnią" housing estate.
Source: Document scan provided by the estate administration.

The estate covers the area of 12.7 hectares, in which over 1600[5] residents live in 754 apartments. It is very interestingly shaped topographically, because all buildings are located on a hill, at a height of about 278 to approx. 301 m above sea level. The buildings on the southern slope are particularly exposed, distinguished by gable roofs, smaller heights and view openings to the Karczówka monastery. Significant land falls in this part of the estate must be overcome by terrain steps and high-slope streets. The estate consists mainly of buildings with a meander system with significant green urban interiors, which are mostly not developed into recreational functions. At the heights of 3, 4 and 5-storey buildings (with the exception of three 11-story buildings in the center of the foundation), the housing estate has a human-friendly scale. The composition of the estate is clear, with a clearly visible main communication route in the form of Króla Władysława Jagiełło street and two main pedestrian routes that lead to the education buildings: Adama Mickiewicza Primary School No. 34 and Local Government Kindergarten No. 34. In the central part of the assumption, there is also a large green recreational area with a playground and a playground. Unfortunately, due to changes in the communication service model, it is currently surrounded by parking spaces, which is clearly presented in the analysis of the communication service system (Fig. 7).

A comparison of the implementation plan (Fig. 2) with photomaps from later years and the current state of the housing estate (Fig. 6, 7) shows the deficiencies in the service and communication infrastructure that occurred during implementation: unrealized commercial and service pavilions and large parking lots. Significant shortages of the service infrastructure were replaced with small commercial and service buildings, inter alia in the north of the housing estate, where the implementation plan was not planned. However, significant shortages in the parking infrastructure and rapid development of the automotive industry have increased the demand for additional parking spaces. Over the years, they were completed chaotically, changing the communication service system. The author distinguishes several ways of organizing parking spaces, by residents, housing cooperatives, private entrepreneurs and city authorities:

- undesignated so-called "wild" parking spaces that degrade space and have a negative impact on its functionality, appearance and safety on foot (Fig. 3),

[5] According to data obtained in the "Domator" Housing Cooperative. Assuming that the average number of residents per apartment is 3 people, the estate has 2 262 inhabitants.

- parking spaces organized by housing co-operatives, separated at the expense of reducing green areas (some parking spaces were created according to the project of the target traffic organization commissioned by co-operatives for the entire housing estate (Fig. 4)),
- parking lots next to commercial and service buildings, which are also used by residents,
- private guarded parking in the western part of the estate, payable on a monthly subscription of 95 PLN gross,
- the multi-level "Park & Ride" parking lot planned by the city for 420 seats, which would act as a transfer parking and communication service for the housing estate (Fig. 5).

Fig. 3. Illegal parking spaces in the housing estate "Pod Dalnią".
Source: Author's photo.

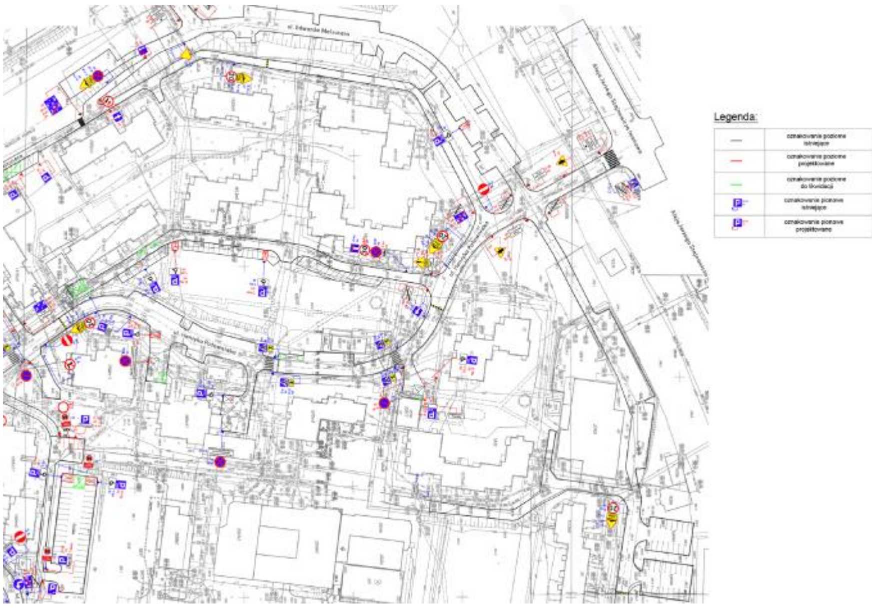

Fig. 4. The project of the target vehicular movement for the "Pod Dalnią" housing estate.
Source: Materials provided by "Domator" cooperative.

Fig. 5. The multi-level "Park & Ride" parking lot planned by the city in the "Pod Dalnią" housing estate.
Source: http://www.um.kielce.pl/programy-i-actions/parkingi-wielopoziomowe-raport/.

A fundamental element of the research of the estate is the urban inventory, in the form of functional and spatial analysis and communication, with particular emphasis on the type and amount of parking spaces. The illustration below (Fig. 6) shows the current functional and spatial structure of the housing estate after changes that have been occurring for almost 30 years since its creation.

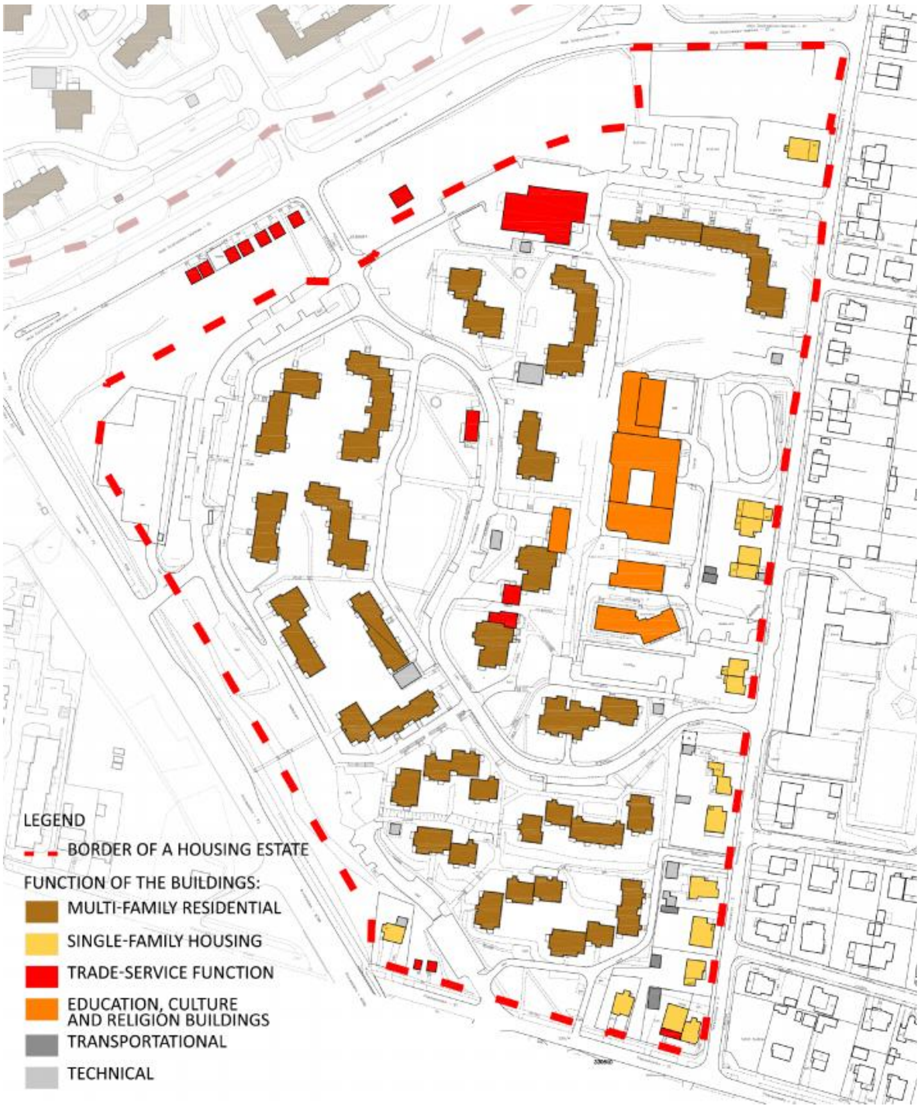

Fig. 6. Functional and spatial analysis of the "Pod Dalnia" housing estate.
Source: Author's.

Commercial and service pavilions that are on the target development plan have not been implemented to date, only small additions to the commercial and service infrastructure of the housing estate are visible. The shortages in the building, however, did not cause a negative tendency, occurring on other housing estates from the second half of the twentieth century, filling gaps in the space with new residential buildings. There is still the possibility of deliberate development of these areas, taking into account functional, spatial and social needs.

In the second place, the author analyzed the communication service system of the housing estate based on archival plans, current maps, field vision and own counting of separate parking stands and parked in unacceptable places of cars (Fig. 7). The counting was carried out on weekdays between 18:00 and 21:00, that is at the time of the day, when the residents return to their place of residence after work.

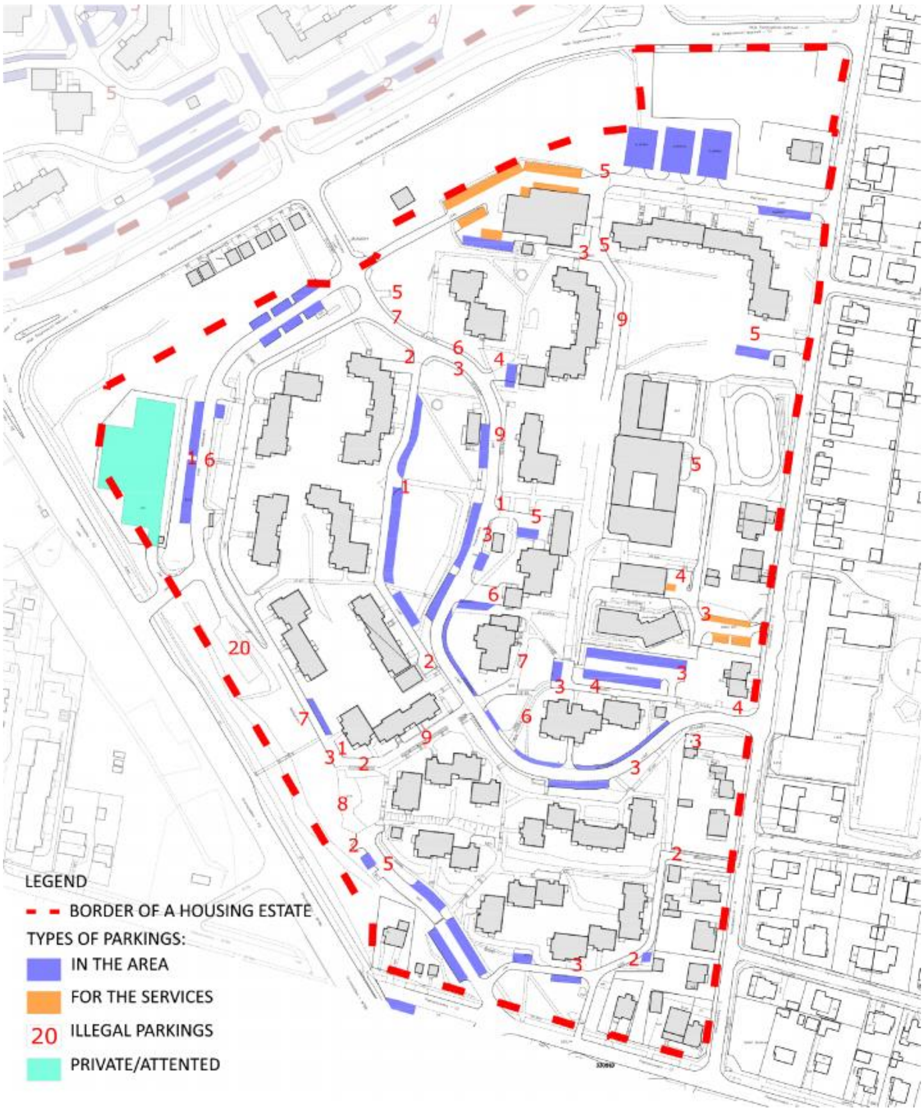

Fig. 7. Functional analysis of the communication system of the "Pod Dalnią" housing estate.
Source: Author's.

The communication service system in the development plan was designed as a loop-extractor [14] and consisted in locating car parks on the outskirts of the team and along the inner street passing through the middle of the housing complex. Thanks to this solution, cars were not introduced into the space between buildings, which created the best opportunities for social bonds. Thanks to this solution, cars were not introduced into the space between buildings, which created the best opportunities for social bonds. Pedestrian routes running along the buildings allowed only emergency entry of the fire brigade or ambulance. Over the years, the development of individual transport and shortages in infrastructure have caused the motorists to take up a number of estate spaces that were intended for green areas and pedestrian communication. Car traffic penetrated into the estate area, but not so strongly due to the topography of the area. Horizontal zoning of pedestrian and car traffic[6], on the basis of which the housing estate project was created, has been disturbed in many places. The project assumed an index of 110 parking spaces per 1000 inhabitants[7], currently there are 162 dedicated places (not including places with services and guarded) per 1000 inhabitants, or 0.49 flat. This is half of the current design indicator, which is at least 1 parking space for one flat. Analysis of the communication service system presents the location and distribution of various types of parking spaces throughout the entire

[6] The necessity of communication and functional zoning depending on the type and intensity of traffic was emphasized in the norm of 1974 [13].

[7] Data from the technical description of the Detailed Implementation Plan of the "Pod Dalnią" housing estate made available by the housing estate administration.

estate. It is worth paying attention to the "scattered" red numbers, indicating the number and location of cars parked in forbidden, unmarked places. In this way, it can be assumed that the demand of the residents of the housing estate is 0.75 parking space per apartment, and after adding private car parks and services, which also benefit residents, this ratio increases to 0.94. The table (Table 1) collates various types of parking spaces and their percentage share[8]. The "Pod Dalnią" housing estate distinguishes itself from other Kielce housing estates with only terrestrial parking spaces.

Table 1. Data summary on the transportation system of the "Pod Dalnią" housing estate.

	The number of flats	**The number of residents**	**The number of parking spots (for the disabled)**					**The number of illegal car parks**	**The number of private car parks**	**The number of car parks for services**
			Sum	**In the area**	**Under ground**	**Garages in the building**	**Freestanding garages**			
Value	754	2 262	366 (11)	366 (11)	-	-	-	**197**	**90**	**58 (2)**
Part %	-	-	100%	100%	-	-	-			
Parking indicator	**0,49**									

Source: Source: Author's.

The "Pod Dalnią" housing estate and other fully planned Kielce housing complexes from the second half of the 20th century are too broad in their structure to deal with the problem of communication service in general and find one suitable solution. The author has divided the estate into urban units in order to carry out detailed research within their borders. The estate was divided into five units based on the spatial layout of buildings, the communication system, the ownership structure of the land, the border of plots and street axes. Separately, the area 2.E was designated and marked in red as a service unit, on which there are buildings of education and culture. The spatial arrangement of units on the map (Fig. 8) shows the layout, the communication service model and the distribution of various types of parking lots within the boundaries of the designated areas. The tabulated combination of data and indicators (Table 2) gives the opportunity to diagnose and compare the scale of the parking problem in each unit.

[8] The division of parking spaces into various types has been made on the basis of ways of storing cars in other settlements in Kielce in order to be able to compare data (type, number of places and percentage share) between them.

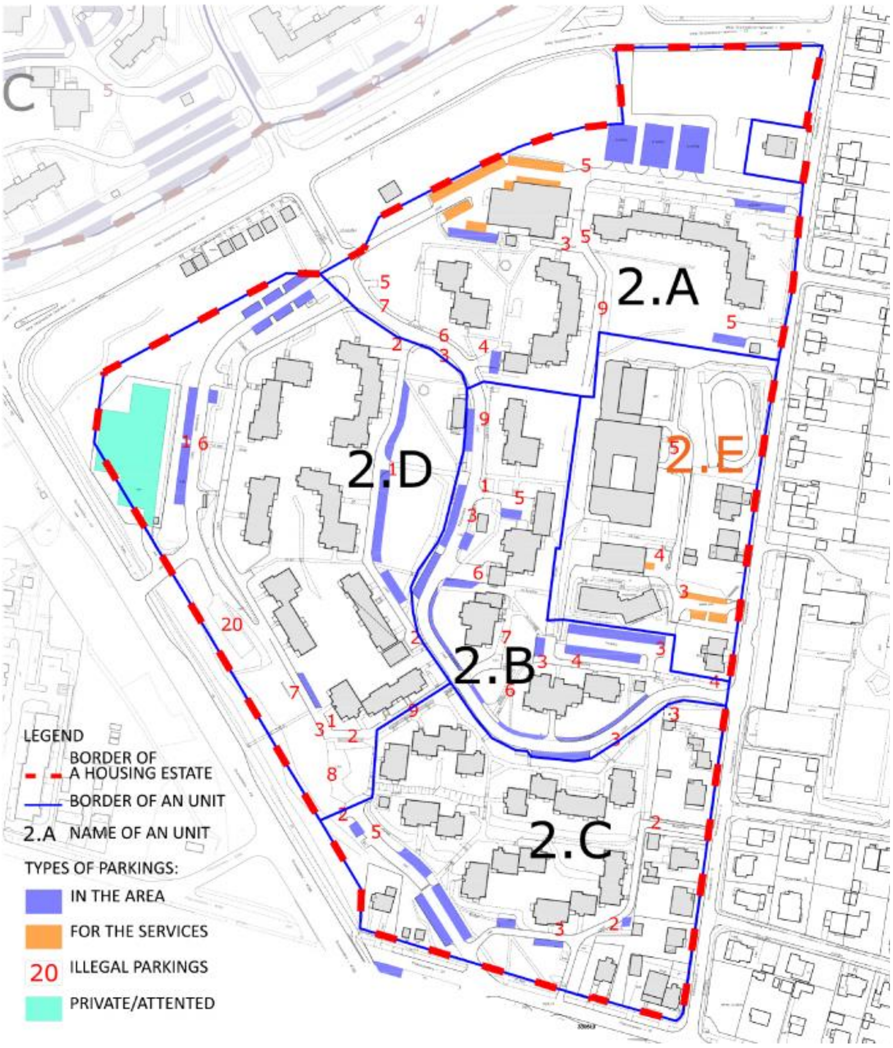

Fig. 8. The original division of the "Pod Dalnią" housing estate into urban units.
Source: Author's.

Table 2. List of data and indicators of urban units of the "Pod Dalnią" housing estate.

Unit number	Unit area	Building area	Building intensity	The number of flats	The number of residents	The number of parking spots (for the disabled)					Parking indicator	The number of illegal car parks	The number of private car parks	The number of car parks for services
						Sum	In the area	Under ground	Garages in the building	Freestanding garages				
2A	31 032 m²	3 814 m² (12%)	0,44	154	462	86	86	-	-	-	0,56	52	-	46 (1)
2B	16 633 m²	2 423 m² (15%)	1,06	183	549	126 (6)	126 (6)	-	-	-	0,69	54	-	-
2C	25 974 m²	4 826 m² (19%)	0,63	177	531	49	49	-	-	-	0,28	26	-	-
2D	36 736 m²	4 380 m² (12%)	0,55	240	720	105 (5)	105 (5)	-	-	-	0,44	53	90	-
2E	16 594 m²	3 987 m² (24%)	0,46	-	-	-	-	-	-	-	-	12		12 (1)
THE SUM OF WHOLE	**126 969 m²**	**19 430 m² (15%)**	**0,59**	**754**	**2 262**	**366 (11)**	**366 (11)**	-	-	-	**0,49**	**197**	**90**	**58 (2)**

Source: Author's.

The table compiles information on building area (percentage share of buildings in the unit's area), building intensity, number of flats, residents and parking spaces. Thanks to the data on the number of flats and separate parking spaces, the author calculated a parking indicator for each unit, thus distinguishing the area 2.B, with the smallest indicator – 0.28 space for a flat and the largest need for the organization of additional parking spaces. The number of unmarked illegal parking spaces, counted during the local vision, provides information about motorized needs and distinguishes individuals and specific spaces that are struggling with their large amount.

The analysis in the spatial (on the map) and tabular form allows for a detailed diagnosis of the problem of communication service in each unit and the distinction of areas that face the biggest parking problem. On this basis, also calculated that the Park & Ride car park planned by the city for 420 places would change the parking situation in the 2.D unit from 0.44 to 2.19 parking space per one flat, and from 0.49 to 1.04 throughout the estate. The analysis also shows the parking lots located near the services and the possibilities of their use in meeting the needs of the communication service of the units. Assuming that the private car park located at the retail pavilion in unit 2.A is fully used by the residents of the unit, its parking situation changes from 0.56 to 0.86 flat. This is an example of a solution that uses an existing communication service infrastructure.

Due to the complexity of the problem under investigation, the author plans to complete urban analysis of units with participatory research, in the form of a survey and interviews with residents. They are aimed at recognizing opinions and needs in terms of the number and availability of parking spaces, the preferred length of access to the car park, the monthly parking fee, the inconvenience generated by the current communication service and meeting residents' ideas for solving the parking problem. The research is planned to be carried out within the boundaries of the spatial units of the housing estate, so that the results are more accurate and complement the urban analysis.

In order to enrich the knowledge about the needs of the residents of the Kielce housing estates studied, the tasks submitted to the Kielce Civil Budget (CB) in all its editions were analyzed (Table 3).

Table 3. List of tasks reported in 4 editions of the budget by residents of housing estates from the second half of the twentieth century.

THE NAME OF THE HOUSING ESTATE	2016											
	TASKS ADMITTED						TASKS UNADMITTED					
	LARGE			SMALL			LARGE			SMALL		
	O	R	I	O	R	I	O	R	I	O	R	I
1. ŚLICHOWICE	1			1	1	1					1	1
2. POD DALNIĄ	1			1	2(1)				1			
3. CZARNÓW		1	1	1	3(1)	1			2	1	1	2
4. HERBY	1				1	2			1			2
5. JAGIELLOŃSKIE	1				1					1		
6. PODKARCZÓWKA	1			1		1						1
7. CHĘCIŃSKIE			1	1	1							
8. AL. LEGIONÓW	3(1)											
9. BARWINEK				1	1				1			
10. KOCHANOWSKIEGO	1			1								
11. CZARNOCKIEGO		1				1			1			
12. ZAGÓRSKA	2	1		2(1)					1			1
13. SANDOMIERSKIE	1			2	1				2			
14. NA SKARPIE							1		1			
15. SADY			1	3							2	1
16. SZYDŁÓWEK					1	1						
17. BOCIANEK										1		
18. SŁONECZNE WZGÓRZE					3	1						
19. UROCZYSKO	1			1								
20. ŚWIĘTOKRZYSKIE												
21. NA STOKU						1			1		2	
NUMBER OF TASKS O,R,I	13 (3)	3	3	15 (4)	15 (4)	8 (1)	1	0	11	3	6	8
THE SUM OF SMALL AND BIG TASKS	19/22			38/56			12/19			17/30		
THE SUM OF ADMITTED AND UNADMITTED	57/78						29/49					
THE SUM OF ALL HOUSINGS' SUBMITTED TASKS	86/127											

THE NAME OF THE HOUSING ESTATE	SUM															ADM.	UNAD.	THE SUM OF THE HOUSING'S TASKS
	TASKS ADMITTED						TASKS UNADMITTED											
	LARGE			SMALL			LARGE			SMALL								
	O	R	I	O	R	I	O	R	I	O	R	I	O	R	I			
1. ŚLICHOWICE	2	3	2	1	5(1)	1	0	1	1	0	1	2	3	10(1)	6	14(1)	5	19(1)
2. POD DALNIĄ	3(1)	1	0	1	3(1)	0	0	0	2	0	0	0	4(1)	4(1)	2	8(2)	2	10(2)
3. CZARNÓW	2	4	6	5(1)	5(1)	1	0	2	7	1	4	4	8(1)	15(1)	18	23(2)	18	41(2)
4. HERBY	2	1	6	1	2	3	0	0	4	0	0	3	3	3	16	15	7	22(0)
5. JAGIELLOŃSKIE	2	0	1	0	3	0	0	1	3	2	0	0	4	4	4	6	6	12(0)
6. PODKARCZÓWKA	5(1)	0	1	1	0	3(2)	0	0	2	0	0	1	6(2)	0	7(2)	11(4)	3	14(4)
7. CHĘCIŃSKIE	0	0	4	1	2	0	0	0	1	0	0	0	1	2	5	7	1	8(0)
8. AL. LEGIONÓW	12(2)	0	0	1	0	1	1	0	2	1	0	0	15(2)	0	3	14(2)	4	18(4)
9. BARWINEK	2(1)	0	2	2(1)	(1)	1	1	0	4	0	0	0	5(2)	1	7(1)	8(4)	5	13(4)
10. KOCHANOWSKIEGO	3	0	1	2(1)	0	0	0	1	0	1	0	0	6(1)	1	1	6(1)	2	8(1)
11. CZARNOCKIEGO	0	1	2	0	0	3(1)	0	1	2	0	0	0	0	2	7(1)	6(1)	3	9(1)
12. ZAGÓRSKA	4	4(1)	2	4(2)	3(2)	1	0	1	0	0	0	1	8(2)	8(3)	4	18(5)	2	20(5)
13. SANDOMIERSKIE	2(1)	1	5	5(2)	3(2)	(1)	0	0	12	1	0	1	8(3)	4(2)	19(1)	17(6)	14	31(6)
14. NA SKARPIE	2(1)	0	0	0	0	0	1	1	1	0	1	0	3(1)	2	1	2(1)	4	6(1)
15. SADY	1	2	2	3	1	1	0	0	2	0	4	2	4	7(1)	7	10(1)	8	18(1)
16. SZYDŁÓWEK	0	0	3	1	8(2)	2	0	0	2	0	1	1	1	9(2)	8	14(2)	4	18(2)
17. BOCIANEK	2	1	0	4(1)	0	0	0	0	0	1	0	1	7(1)	1	1	7(1)	2	9(1)
18. SŁONECZNE WZGÓRZE	2(1)	1	0	1	5	2	0	0	1	0	1	0	3(1)	7	3	11(1)	2	13(1)
19. UROCZYSKO	5(1)	0	2	3	0	0	0	0	1	2	0	0	10(1)	0	3	10(1)	3	13(1)
20. ŚWIĘTOKRZYSKIE	2(1)	0	0	0	1	0	1	0	0	0	0	1	3(1)	1	1	3(1)	2	5(1)
21. NA STOKU	3(1)	4	1	4	2	1	0	1	2	0	3	1	7(5)	10(2)	5	15(7)	7	22(7)
NUMBER OF TASKS O,R,I	56 (11)	23 (1)	40	40 (13)	44 (13)	21 (5)	4	9	49	9	15	18	109 (24)	91 (14)	128 (5)			
THE SUM OF SMALL AND BIG TASKS	119 (12)			105 (31)			62			42								
THE SUM OF ADMITTED AND UNADMITTED	224(43)/306						104/208									224 (43)	104	
THE SUM OF ALL HOUSINGS' SUBMITTED TASKS	328/514												328(43)			328(43)		328(43)

Source: Author's.

Residents of the "Pod Dalnią" housing estate submitted 10 projects during four editions, including 4 for education (E), 4 recreational areas (R) and only 2 for technical and communication infrastructure (I). Reported infrastructure tasks related to large, expensive parking infrastructure projects, among others a task named by the applicants "Multilevel parking lot of our dreams", therefore they were not allowed to vote already at the verification stage. The rest of the submitted tasks show the demand for a recreational space on the estate. The results of the analysis also provide a lot of information about the activity of the inhabitants of Kielce block settlements and their participation in efforts to change their immediate environment.

Summary and conclusions

The presented study is an important source of information on the state of the Kielce housing estate from the second half of the 20th century "Pod Dalnią" mainly in the spatial and communication aspect, and forms the basis for subsequent stages of research. The analyzes carried out allowed to identify one of the most serious problems in the housing estate - a parking problem, whose monitoring is recommended in the "Transport plan for the City of Kielce ...".

Based on the research carried out, the author formulated guidelines that are planned to be extended in the future with more detailed proposals for solving the parking problem and directions of housing development in the context of sustainable mobility:

- Monitoring and analysis of the communication service model and the parking situation on the estate, which is the basis for the development of specific parking policy measures and transport plan. (Fig. 7, Tab. 1)
- Division of the housing estate into smaller urban units in order to carry out detailed analyzes of their communication service. The housing assumptions of the second half of the twentieth century are too extensive in their structure to deal with the parking problem in general and try to find one suitable solution. (Fig. 8, Table 2)
- Based on the global trends of decreasing the share of car travel and parking indicator (up to 0.5 parking spaces per flat) [15] and recommended in the "Transport Plan for the City of Kielce ..." indicator at 0.75, determining the parking indicator for the housing estate that will be saved in planning documents for this area. The author proposes to determine the maximum indicator of the number of parking spaces per apartment (and not so far in Polish planning records - the minimum indicator), in order to avoid oversupply of parking spaces and not to limit spatial development of the housing estate. Its determination should take into account the spatial and communication status of the estate, its development potential, user preferences and the availability of alternative means of transport.
- Supplementing the strategic and planning documents of the city with a broader approach to the development of bicycle infrastructure, public transport and pedestrian space, and the promotion of alternative means of transport for the car. In addition, the author recommends the creation of a plan for revitalization and development of the housing estate, because the spatial policy of the settlements from the second half of the 20th century in Kielce is in no way limited by planning documents, in the form of local spatial development plans [15].
- On the basis of urban analyzes and surveyed preferences of the residents, designation of areas for the construction of parking lots in the border of the estate. At the same time, it is necessary to limit the number of parking spaces in the streets and in estate interiors. The indicated parking lots should be part of the overall plan for revitalization of the housing estate and indicate the entities that manage these areas.
- Restoration of balance and proper segregation of car, bicycle and pedestrian traffic, thus limiting the penetration of car traffic into the housing estate. The basis for this assumption is the detailed urban research of the estate carried out by the author, supplemented soon with participatory research and other activities of the sustainable transport plan conducted and financed by the City of Kielce.
- Introduction of regulations in the form of cooperative regulations, markings (signs or belts dividing parking places), parking fees, identifiers or barriers for better organization of communication service, as well as control of respecting these regulations and regulations.
- Collaboration between all entities responsible for the estate area, i.e. community management, cooperative, municipal authority, residents, private entrepreneurs, institutions and non-governmental organizations operating in its territory, in order to achieve the objectives of transport policy and sustainable development of the housing estate. The main leader of the transport policy should be the City of Kielce, with the possibility of financing policy measures from own resources or EU funds, while the estate manager (housing communities, cooperative) should carry out tasks in their area, cooperating with the self-government bodies of Kielce and institutions and organizations operating on the estate. Such cooperation will be possible when the housing estates become auxiliary units of the Kielce commune and will conduct financial management within the city budget. At present, the city does not have an administrative division into housing estates, which means that residential areas are not fully managed, heavily divided by ownership, with modest budgets for revitalization activities.

Based on the above guidelines and planned detailed solutions to change the model of communication service, the author seeks to determine the strategy of transformations and development directions of the housing estate. With the modern increase of spatial mobility, it is important to increase the communication accessibility of the housing estate, improve the quality of life of residents and the quality of public space, where you can move safely and comfortably.

References

[1] Zespół Doradców Gospodarczych TOR, Polska Organizacja Branży Parkingowej, Parkingi a transport zbiorowy w miastach, Warszawa, 2017.
[2] E.D. Niezabitowska, Metody i techniki badawcze w architekturze, Wydawnictwo Politechniki Śląskiej, Gliwice, 2014.
[3] A.Szarata (Eds.), Plan mobilności dla miasta Kielce i kieleckiego obszaru funkcjonalnego, Kraków, 2016.
[4] G. Wojtkun, Osiedla mieszkaniowe w strukturze miasta XX wieku, Wyd. Uczelniane Politechniki Szczecińskiej, Szczecin, 2004.
[5] A. Rębowska (Eds.), Strategie rehabilitacji blokowisk, Instytut Rozwoju Miast, Kraków, 2006.
[6] K. Gorczyca, Wielkie osiedla mieszkaniowe – diagnoza stanu obecnego, podejmowane działania rewitalizacyjne, w: W. Jarczewski (Eds.), Przestrzenne aspekty rewitalizacji, t.4, Instytut Rozwoju Miast, Kraków, 2009.
[7] E. Szafrańska, Wielkie zespoły mieszkaniowe – ich przemiany i miejsce w strukturze społeczno-przestrzennej współczesnego miasta. Przykład Łodzi, w: J. Słodczyk, A. Dembicka-Niemiec (Eds.) Funkcje miast jako czynnik kształtowania przestrzeni miejskiej, Opole, 2010.
[8] J. Słodczyk, Geneza i rozwój osiedli blokowych, w: I. Jażdżewska (Eds.), Osiedla blokowe w strukturze przestrzennej miast. XXIII Konserwatorium Wiedzy o mieście, Wyd. Uniwersytetu Łódzkiego, Łódź, 2010.
[9] K. Bieda, Parkingi na osiedlach mieszkaniowych, Teka Komisji Urbanistyki i Architektury PAN, Tom X, Kraków, 1976.
[10] E. Szafrańska, Możliwości przekształceń wielkich osiedli mieszkaniowych w mieście postsocjalistycznym w Polsce, Studia miejskie. 11 (2013) 39-53.
[11] Ministerstwo Infrastruktury i Rozwoju, Ustawa o rewitalizacji z dnia 9 listopada 2015 r, Warszawa, 2015.
[12] Urząd Miasta Kielce, Biuro Planowania Przestrzennego, Aktualizacja Lokalnego Programu Rewitalizacji obszarów miejskich, poprzemysłowych i powojskowych w mieście Kielce na lata 2014-2020. Kielce, 2016.
[13] Regionalny Ośrodek Badania Opinii Publicznej Dobra Opinia, Opinie mieszkańców Kielc na temat projektu budowy parkingów wielopoziomowych na obrzeżach wielorodzinnych osiedli mieszkaniowych w kontekście ich rewitalizacji, Kielce, 2016.
[14] K. Lewicka, J. Michałowska-Furman, F. Sobierajska, Układy komunikacji w zespołach mieszkaniowych, Wydawnictwo Akcydensowe, Warszawa, 1978.
[15] E. Dyk, A. Szumilas, Parking problems in shaping a housing w: 5th International Multidisciplinary Scientific Conference on Social Sciences&Arts SGEM 2018, Conference Proceedings,Volume 5, Urban Planning, Architecture and Design ISSUE 5.1, Wiedeń, 2018, s. 251-258.
[16] S. Gzell, Polskie miasto w stanie przejściowym: między zwartością a rozproszeniem, w: I. Jażdżewska (Eds.), Duże i średnie miasta w okresie transformacji, Wydawnictwo Uniwersytetu Łódzkiego, Łódź, 2009.

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THE USE OF OUT-OF-DATE FROZEN FOOD AS A SUBSTRATE FOR BIOGAS IN ANAEROBIC METHANE FERMENTATION

Abstract
The declining quantity of fossil fuels and the increasing demand for energy are two of the many problems that are affecting current times. This is why there is an increasing interest in and introduction of operations related to renewable sources of energy. One of many such possibilities is to conduct the biomass methane fermentation process and to obtain clean energy in the form of biogas. The aim of this research was to analyse the biogas-generating potential (Biochemical Methane Potential) of out-of-date frozen products in the laboratory anaerobic fermentation process and the near-infrared method with appropriate Biochemical Methane Potential calibration. The results obtained showed that selected frozen products are an excellent material for use as substrates resulting in the production of high quality biogas. It gives the opportunity to continue research, mainly in terms of applications, e.g. for biogas plants, using other available products on the market and the selection of their mixtures.

Key words
renewable source of energy, biogas, methane fermentation, methane, inoculum, BMP, out-of-date frozen food

Introduction

With the advancement of civilization and the economy, the need for everyday comfort and the satisfaction of the physiological needs of people is growing, among which, above all, food access can be distinguished. This is conditioned by many factors, including the degree of advancement of agriculture or food processing. New sales markets are created and quick and easy access to the purchase of goods, and fairly new food products are introduced onto the market, not always to the satisfaction of all consumers. In developed countries, there is a significant overproduction of food in relation to actual demand (domination of supply over demand), and, at the same time, an increasing interest in the diversity of the food products made available by competing producers. This leads to the wasting of excess quantities of food that could be used for consumer purposes. This food becomes a potential waste, so it is worth looking for methods of its effective use [1, 2]. Every year, according to the Federation of Polish Food Banks, nearly 1.3 billion tons of food is wasted, which is about 1/3 of the total food produced (Europe: approx. 100 million tons, Poland: approx. 9 million tons, of which about 6.6 million tons comes from the food industry) [3]. Waste food is nothing more than a simultaneous waste of energy and water at the stage of production, transport and further management, and also leads to the creation of more waste [4]. This is due to many reasons: a lack of accurate estimation of production volume, damage to the production line, changing consumer preferences, inadequate food storage, packaging defects, natural disasters and many other causes, the most frequent being out-of- food products [1; 2].

Nowadays, so-called "Convenience food", mainly due to the seasonality of some raw materials or the ease of storage are very popular. This is aimed at giving products a greater availability by processing which prolongs their shelf live. One method of food preservation is the low temperature treatment: the cooling and freezing of food. While cooling extends the shelf life of products, this time is comparatively short. Freezing of products ensures a long shelf life with no loss of valuable ingredients. Thus, vegetables and fruits are very popular when subjected to freezing on a mass scale [5, 6, 7]. The problems mentioned above concerning the quality and durability of products lead to the generation of food or waste biomass in huge quantities. Not only are people obliged to optimize the production conditions, but also to develop methods and technologies that will facilitate the re-use of waste biomass and at the same time to reduce its negative impact on the environment [8].

Biomass energy is one of the most popular renewable energy sources, because, among other reasons of its availability. The energy stored inside is transformed into different forms of biofuels: solid, liquid and gaseous. One of the perfect conversion methods seems to be the methane fermentation process in which organic

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multiparticulates are broken down then biodegraded by microorganisms, so that in the end, one of the valuable energy carriers, i.e. biogas, is obtained [9, 10]. It consists primarily of methane (40-75%) and carbon dioxide (25-60%), as well as other gases present in small amounts such as nitrogen, hydrogen sulphide, oxygen, hydrogen, carbon monoxide and others. CH_4 in and of itself is a high-energy gas, and its content shows the quality of the biogas - the greater its share of biogas, the higher the fuel's heat of combustion. This composition depends on the conditions of the fermentation process [11, 12]. Ensuring optimal process conditions is the key to achieving the most satisfying results. Among the factors that can be distinguished are: pH, temperature, particle size, mixing, nutrient concentration, substrate moisture and inhibitors, as well as the proper selection of substrates or inoculum [13]. Special attention should be given to nature of substrates, including the right choice of substrates, the way they are prepared for the process (size, dry or wet material), retention time and loading rate. These factors affect the digestion process efficacy and the same gas production rate [14]. The optimal pH range for efficient anaerobic digestion is 6.8-7.2. Lower pH lead to reduce growth rate of methanogens, in turn higher value of pH (alkaline) have influence on disintegration of microbial flux [15]. Temperature affects the nature of microorganism metabolism, biomass composition, dietary requirements and reaction speed. For suitable groups of organisms, the increase in temperature affects the rate of growth, and too high a temperature (above the optimal value) causes protein denaturation [16]. The optimum mixing ensures maximum biogas yield by ensuring better contact of bacteria with substrate particles. On the other hand, too intensive mixing can cause foaming, sedimentation, frothing materials and scumming [17]. In addition, the C / N ratio is often specified. Its inadequate value may release of high volatile fatty acids accumulation, high total ammonical nitrogen or free ammonia. Many years of research indicate that the most optimal range for bacterial growth is 20-30 and it is variable depending on the introduced substrate [15]. The industrial scale process itself has to be optimized to increase the production of biogas and methane at the same time. Biochemical Methane Potential tests are becoming more and more popular, because they characterise a given substrate before it is introduced into the fermentation chamber. It indicates what amount of methane can be potentially produced from a given substrate. It measures the maximum amount of biogas or methane produced per gram of volatile solids ($cm^3_{CH4} \cdot g_{VS}^{-1}$), contained in the organics used as substrates in anaerobic methane fermentation. BMP can measure the methane potential of different substrates as well as pure, individual products and their mixtures. There are a few experimental methods available but BMP analysis is the most successful, thanks to their easy setup, conduction and the useful information obtainable from them for optimizing the design or operation of an anaerobic digester [18, 19]. The benefits from methane fermentation lead to an increase in interest in the use of this technology. Correct system design and precise planning are really necessary to maximize efficiency. Biochemical methane potential is relatively cheap, repeatable and does not require heavy labour and provides a real appraisal of the anaerobic digestibility of the substrate [20].

The presented paper displays the results obtained in the laboratory BMP tests of the mesophilic periodic methane fermentation of expired frozen vegetables under different organic loads and with the use of two different inoculums. Moreover, experimental results are compared with Near Infrared Spectroscopy (NIR) analyses with an appropriate empirical calibration delivered by the NIRFlex N-500 SOLID apparatus (Buchi). The CHNS analysis of substrates made it possible to relate the C/N quotient of each substrates to its methane production potential. The biogas production efficiency was strongly influenced by the inoculum type, which suggests that microorganisms of methane fermentation need to be seasoned in order to use the substrates efficiently. The anaerobic fermentation of the examined out-of-date frozen products lead to the production of biogas characterized by its high methane content which makes them a very attractive substrate for biogas plants.

Materials and methods

The biogas-generating potential was investigated for four selected out-of-date frozen products, i.e. carrot, green peas, yellow beans and mixed vegetables (composition: 35% carrots, 25% green peas, 20% corn, 10% celery, parsley 10%). At the same, time two types of inoculum were used: fermented sewage sludge, taken directly from the installation of mesophilic methane fermentation located in the Wastewater Treatment Plant in Lodz (WTP; process temperature about 37°C); digestate from agricultural and utilisation biogas plant (BP) (mainly substrates: apple pomace, decoction and waste from the food industry, process temperature 44°C).

In order to determine the suitability of frozen vegetables as methane fermentation substrate, the C/N ratio was analysed by elemental composition analysis (CHNS) with CE Instruments, the NA-2500 apparatus. The above-mentioned products were defrosted and pre-treated mechanically – only by milling. The prepared substrates were added to the fermentation mixture (without drying). Process conditions: one-stage, periodic wet fermentation with periodic mixing, carried out in flasks with a working capacity of 500 cm^3 in thermostated incubators equipped with a biogas volume measurement system (process temperature 37-40°C). The following load of wet substrates: 20, 30 and 40 $g \cdot dm^{-3}$ and zero tests (the inoculum itself) were investigated, it corresponds to the volatile solids (VS) concentration of individual vegetables in the fermentation mixture (in $g_{VS} \cdot dm^{-3}$): carrot (2,00; 3,00; 3,99), mixed vegetables (3,02; 4,53; 6,03), green peas (5,05; 7,58; 10,10), yellow bean (2,61; 3,91; 5,22). The composition of the produced biogas was measured with gas chromatography for CH_4 content (gas chromatograph SRI Instruments, 8610C Compact GC). The pH measurement in fermentation mixtures was carried out with WTW SenTix41 pH electrode. The results obtained of biogas production efficiency were compared to Biochemical Methane Potential (BMP) analyses with a near-infrared spectrometer (NIR FLEX N-500 SOLID). The BMP was assessed by near-infrared spectroscopy (BMPNIR) combined with rapid and innovative calibration (FlashBMP®) developed by Ondalys (Chemometrics – Data Analytics) and commercialized by Buchi (Switzerland) [21, 22]. The results of measurement are given in cm^3 of methane per g of VS. As to experimental the total volume of biogas was measured than background volume was subtracted. Then on the basis of methane concentration in biogas the total amount of methane produced was calculated and divided by volatile solids added with a substrate. That gives results in cm^3 of methane per g of VS.

Results and discussion

As the first part of the research, differences in biogas production from the inoculum were checked (Fig. 1). There is a significant difference between these sludges, the almost five-fold greater biogas production (WTP: 235 cm^3, BP: 1220 cm^3) was observed, furthermore the biogas BP sludge was produced for a longer period. This difference is directly related to the intake site, i.e. the WTP sludge was collected from the sludge degassing tanks after the fermentation process, and the other directly collected from the fermentation chamber. The obtained volume of biogas from the inoculum was subtracted from the biogas volume produced in the BMP tests which was the basis for checking which type of inoculum would prove to be more effective in testing – under the same process conditions.

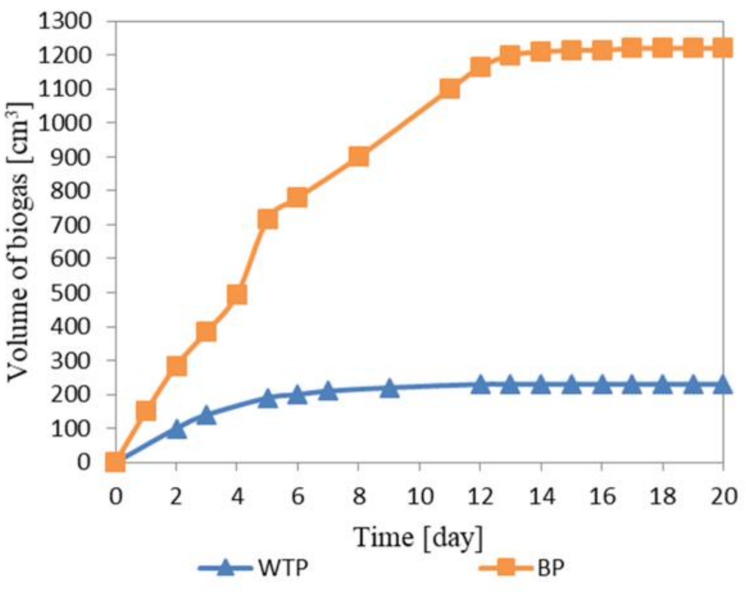

Fig. 1. Biogas production from two inoculums: 1) Wastewater Treatment Plant (WTP); 2) biogas plant (BP)
Source: Author's

The use of out-of-date frozen products as substrates gave positive results taking into account the quantity and quality of biogas produced. Figure 2 shows examples of process results for trials with a load of 40 $g \cdot dm^{-3}$. The most intensive production was observed up to 5-6 days. Biogas production on the WTP sludge lasted a maximum of 12 days, while on the inoculum from BP, it stopped after 17-20 days. Biogas production was slightly more efficient in the fermentation mixtures with inoculum from BP.

The BP sludge more effectively used the added substrate (carrot, mixed vegetables) and, as a result, larger volumes of biogas were obtained from the same loads of the tested vegetables (Figure 3). Therefore, the fermentation process for peas and beans was continued only on this sludge. The selection of an appropriate inoculum as well as the acclimatization of sludge to the used substrate plays an important role in the methane fermentation process, this fact is confirmed in the paper by Yin et al. dealing with volatile fatty acid production from food waste in the methane fermentation [23]. On the other hand, Koch et al. suggest that the choice of inoculum had no significant impact on the specific methane yield of the tested substrates. They also suggest that the degradation is faster for those inocula already adapted to the substrate tested while efficiency stays the same [24].

In terms of the amount of obtained biogas, peas turned out to be the best of the tested vegetables (max 2945 cm^3). The organic load of the substrates is another factor influencing the process (Figure 3), with each increase a larger biogas production was noted. However, these were not the highest VS loads that could be used, the processes ran in the stable conditions, where the initial pH was within in the range of 7.54-7.76; and the final 7.34-7.57 (optimal, comparable level). Czerwińska and Kalinowska suggest that the optimal range is between 4.5-7.5 (6.8-7.2 for the methanogenic phase), but the results are only slightly out of range. With an excessive amount of VS, the process could be disturbed or completely stopped due to volatile fatty acid accumulation [13]. Sosnowski et al. reports that during fermentation an accumulation of volatile fatty acids (VFA) caused a decrease in pH and strongly inhibited gas production. The more optimal the conditions are provided for bacteria, the higher the percentage share of methane in biogas can be obtained [25].

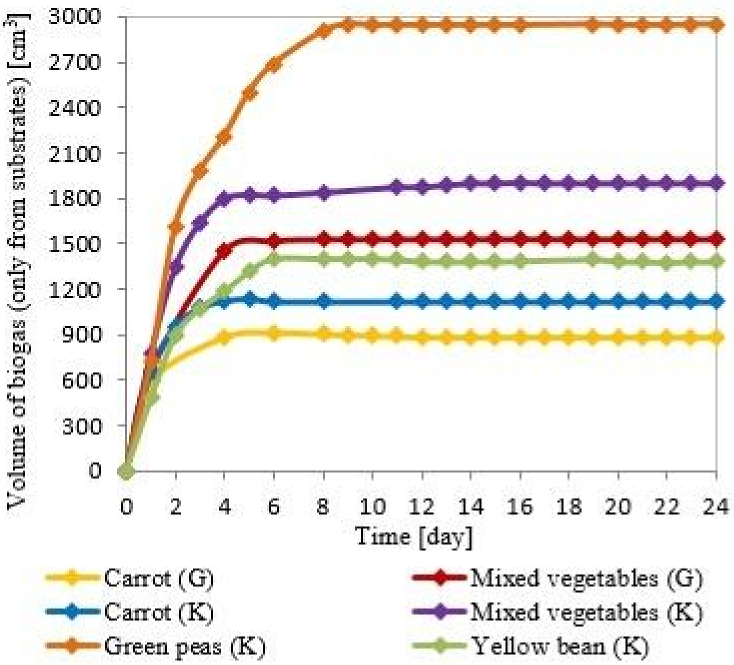

Fig. 2. Biogas production from out-of-date frozen food without inoculum. Fermentation mixtures with a load of 40 $g \cdot dm^{-3}$ (K – BP, G – WTP)
Source: Author's

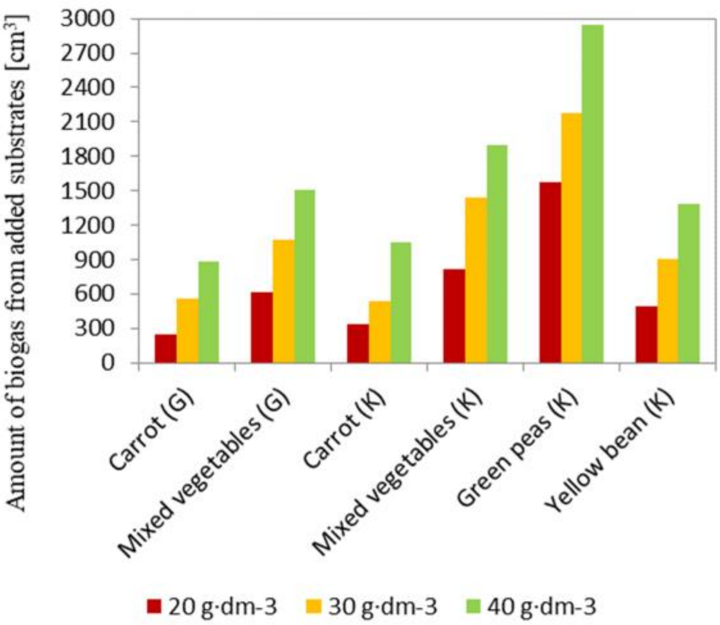

Fig. 3. Volume of biogas only from out-of-date frozen food (without inoculum); Fermentation mixtures with a load in all cases (K – BP, G – WTP)
Source: Author's

Table 1 shows the percentages of CH_4 from the individual fermentation series. In terms of quality (averaging results), the biogas plant sludge was also more attractive with a methane content of 68.05-70.61%, although these values are comparable. The addition of substrate contributed to the enrichment in methane by about 0.2 to 18.6%. Such a high share of the most important component (from 63.98 to 78.18%) indicates the possibility of obtaining high-quality biogas from frozen food. Jędrczak presented the range of methane content in biogas between 40-75%, while Kaźmierowicz in presenting all chemical components of agricultural biogas, shows that methane can be in the range of 52-85% [26, 12]. Comparing the obtained results, it is stated that they belong to the upper range.

The optimal value of the C/N ratio of substrates, indicated by many literature positions, is in the range of 10-30, variable depending on the source. Głodek, as the optimal one, gives exactly the above scope (10-30), in turn Czerwińska and Kalinowska and Jędrczak reduce this range, i.e. 10-25. Deubelin and Steinhauser, on the other hand, state that it should be in the range of 16-25 [28, 13, 12, 27]. Figure 4 shows the methane yield in relation to the C/N ratio for each of the tested substrates. The carbon-to-nitrogen ratio of all examined substrates is in the above mentioned range, once near the highest values - carrot (29.32) or the lowest as in the case of green peas (10.5). However, by comparing the results to the limits presented by Deubelin and Steinhauser in 2011, only the vegetable mix (17.98) would comply with the requirement [27]. The type of substrate used also affects the stability and efficiency of the process. There are products on the market with a diverse elemental composition (and the same C/N ratio) and they also differ in the DS and VS content. It is worth looking for products that will most effectively affect the fermentation process - not only individual substrates, but also all kinds of mixtures. Both mixtures of substrates as well as the widely understood co-fermentation seem to be a more effective solution. The paper by Sadecka et al. shows the many advantages of co-fermentation: the possibility of five times more biogas production, a higher degree of VS decomposition and less contamination of digestate suspensions [29]. Co-fermentation is more favourable than mono-fermentation also according to Sosnowski et al., which additionally draws attention to the benefits in terms of energy saving and environmental protection [25].

Table 1. Range of methane share in all series

Substrates	Inoculum	Methane share [%]
Carrot	WTP	63,98 - 75,16
Mixed vegetables		65,85 - 78,18
Carrot	BP	69,59 - 73,82
Mixed vegetables		67,24 - 68,25
Green peas		74,26 - 74,84
Yellow beans		73,06 - 73,10
Sludge from WTP		63,62 - 72,08
Sludge from Konopnica (BP)		68,05 - 70,61

Source: Author's

However, the study showed that the green peas with the lowest C/N ratio (Figure 4) , close to the lowest range indicated above, was the most efficient substrate in terms of methane production per 1 gram of VS delivering close to 450 $cm^3{}_{CH4} \cdot g_{VS}{}^{-1}$. Whereas the carrot, having a C/N ratio almost going above the optimal ranges, was characterized by the lowest methane production, 276 $cm^3{}_{CH4} \cdot g_{VS}{}^{-1}$. Nevertheless, the direct correlation between C/N ratio and methane yield was not found. Dioha et al. show in the article, the correlation of biogas yields of tested substrates with C/N ratios, based on the part of waste such as rice husks, sugar, bagasse, grass silage, animals excreta. In fact, for the range of C/N for the substrates above 30 and from the lower range 10, much smaller volumes of biogas were obtained (for C/N: 47, 53, 82, 10; respectively: 280, 200, 150, 28 $cm^3 \cdot g_{VS}{}^{-1}$). In turn, the higher production of biogas was characterized by the substrates with C/N: 26; 25; 24; 15; 13 (biogas: 650, 350, 700, 350, 500 $cm^3 \cdot g_{VS}{}^{-1}$). However, the results of the obtained biogas in these ranges are divergent [30]. As was shown there is no optimal universal C/N ratio for methane fermentation It has the effect on methane production and in the case of too low a value, can result in ammonium inhibition and if too high the nitrogen supply can be not enough to satisfy the metabolic needs of microorganisms. since the C/N ratio cannot be the basis on which the substrate composition can be optimized.

The laboratory BMP tests may not be extremely laborious and the obtained results the most reliable ones but nevertheless they require a lot of time. Utilisation of out-of-date food results in the unstable substrate supply in terms of composition and diversity. The near-infrared spectra analysis with appropriate calibration can be useful for predicting methane yields in a matter of minutes and can potentially be implemented as an online measurement as suggested by Ward [31]. According to Preys S. et al. a long-term series of laboratory tests are indispensable to obtain the proper calibration curve of NIR results and Biochemical Methane Potential [18]. Nevertheless, accurate and approved calibrations are available on the market (i.e. https://www.buchi.com/en/products/ nirsolutions/nirflex-n-500).

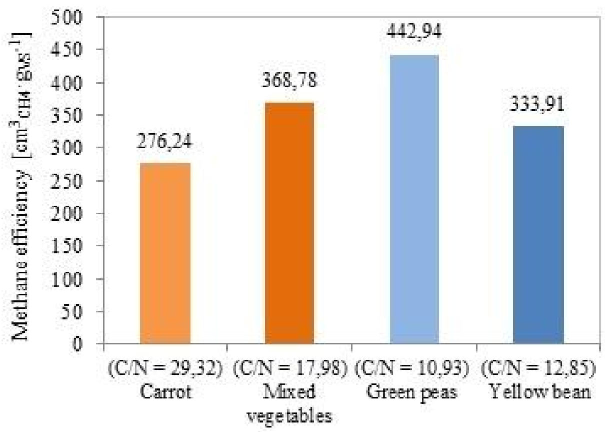

Fig. 4. Methane efficiency in relation to the C/N quotient of each substrates – taking into account the results of all series
Source: Author's

Table 2 presents the results obtained from the NIR analysis returned as cm^3 CH_4 per gram of VS delivered with a substrate. The obtained values were compared with the averaged results of the experimental BMP process (also presented in Table 2).

Similar values were recorded for the vegetable mix and yellow bean. The results obtained from the fermentation process for green peas (442.94 $cm^3_{CH4} \cdot g_{VS}^{-1}$) outperformed the significantly predicted value from NIR analysis. Unfortunately, the predicted result for carrots was not obtained in the experiment, and the difference was about 80 $cm^3_{CH4} \cdot g_{VS}^{-1}$. Nevertheless, the investigated organic loads were not the highest ones and these results are valuable information for the calibration and validation of processes. Esposito G. et al. draw attention to the fact that such tests are relatively inexpensive, easy to perform and repeatable, despite the criticisms they face [19].

Table 2. Comparison NIR analysis BMP with results of experiments in all series (methane fermentation)

Substrates	BMP (NIR analysis)	Inoculum	Amount of methane per VS added (methane fermentation)	
			Experimental results	Average value
	$cm^3_{CH4} \cdot g_{VS}^{-1}$		$cm^3_{CH4} \cdot g_{VS}^{-1}$	$cm^3_{CH4} \cdot g_{VS}^{-1}$
Carrot	**356,85**	WTP	264,08	**276,24**
		BP	288,4	
Mixed Vegetables	**353,48**	WTP	329,29	**368,78**
		BP	408,27	
Green Peas	**373,34**	BP	442,94	**442,94**
Yellow bean	**300,48**	BP	333,91	**333,91**

Source: Author's

Summary and conclusions

The obtained results indicate that out-of-date frozen food is a good material for use as a substrate in the methane fermentation process. It is worth noting that the presented values represented only four selected products (carrots, green peas, yellow beans and mixed vegetables) from among the many available on the market. Each of them will have a different influence on the course and final result of the process. The advantage of using such products is that they do not require complicated pre-treatment. In the final effect, one can get high-methane biogas, while reducing the waste from the food sector.

This type of research is of an application nature, however, such materials are used in biogas plants in much larger volumes. The biogas production efficiency will be influenced by such factors as: type and concentration of materials in the digester, pre-treatment, the type of inoculum and others.

References

[1] B. Bilska, W Grzesińska, M. Tomaszewska, M. Rudziński, Marnotrawstwo żywności jako przykład nieefektywnego zarządzania w gospodarstwach domowych, Stowarzyszenie Ekonomistów Rolnictwa i Agrobiznesu, Roczniki Naukowe. 17 (2014) 39-43.

[2] M. Śmiechowska, Zrównoważona konsumpcja a marnotrawstwo żywności, Annales Academiae Medicae Gedaensis. 45 (2015) 89-97.

[3] Raport Federacji Polskich Banków Żywności. Nie marnuj jedzenia, Banki żywności, Warszawa, 2015.

[4] A. Dąbrowska, M. Janoś-Kresło, Marnowanie żywności jako problem społeczny, Handel Wewnętrzny. 4 (2013) 14-26.

[5] V. Gaukel, Cooling and Freezing of Foods. Reference Module in Food Science, 2016.

[6] J. Doroszkiewicz, Współczesne techniki zamrażania: Mrożona żywność wygodna – ogólna charakterystyka, Katedra Techniki Cieplnej, Politechnika Gdańska, 2006.

[7] J. Typrowicz, Metody utrwalania i przechowywania żywności. Zespół Szkół Gastronomicznych i Przemysłu Spożywczego, Przemyśl, 2006.

[8] J. Ryń, Współczesne techniki zamrażania – Jakość i trwałość mrożonej żywności. Wydział Mechaniczny, Politechnika Gdańska, 2008.

[9] I. Niedziółka, M. Szpryngiel, Możliwości wykorzystania biomasy na cele energetyczne, Inżynieria Rolnicza. 1 (2014) 155-164.

[10] P. Bartoszczuk, Opłacalność energetycznego wykorzystania energii elektrycznej z biologicznych nośników energii oraz wiatru, W: D. Niedziółka, Zielona energia w Polsce, CeDeWu, Warszawa, Wyd. I, 2012.

[11] W. Podkówka, Z. Podkówka, A. Kowalczyk-Juśko, P. Pasyniuk, Biogaz rolniczy, odnawialne źródło energii. Teoria i praktyczne zastosowanie, Powszechne Wydawnictwo Rolnicze i Leśne, Warszawa, 2012.

[12] A. Jędrczak, Biologiczne przetwarzanie odpadów, Wydawnictwo Naukowe PWN, Warszawa, 2007.

[13] E. Czerwińska, K. Kalinowska, Warunki prowadzenia procesu fermentacji metanowej w biogazowni, Technika Rolnicza Ogrodnicza Leśna. 2 (2014) 12-14.

[14] M. Noraini, S. Sanusi, J. Elham, Z. Sukor, K. Halim, Factors affecting production of biogas from organic solid waste via anaerobic digestion process: A review. Solid State Science and Technology. 25(1) (2017) 29-39.

[15] J. Kainthola, A. S. Kalamdhad, V. V. Goud, Optimization of methane production during anaerobic co-digestion of rice straw and hydrilla verticillata using response surface methodology, Fuel. 235 (2019) 92-99.

[16] E. Maleki, A. Bokhary, B. Q. Liao, A review of anaerobic digestion bio-kinetics, Reviews in Environmental Science and Bio/Technology. 17 (2018) 691-705.

[17] K.Latha, R. Velraj, P. Shanmugam, S. Sivanesan, Mixing strategies of high solids anaerobic co-digestion usin food waste with sewage sludge for enhanced biogas production, Journal of Cleaner Production. 210 (2019) 388-400.

[18] S. Preys, J. Lallemand, S. Roussel, Flash BMP®: Calibration for the biochemical methane potential (BMP) of solid organic waste using NIRS [online], Book of Abstracts, [watch: 02 march 2018], available in: https://proceedings.galoa.com.br/nir-abstracts/papers/flash-bmpr-calibration-for-the-biochemical-methane-potential-bmp-of-solid-organic-waste-using-nirs?lang=en#sthash.5Jh5nQTt.dpuf, 2015.

[19] G. Esposito, L. Frunzo, F. Liotta, A. Panico, F. Pirozzi, Bio-Methane Potential Tests To Measure The Biogas Production From The Digestion and Co-Digestion of Complex Organic Substrates, The Open Environmental Engineering Journal. 5 (2012) 1-8.

[20] L. Moody, R. Burns, W. Wu-haan, R. Spajic, Use of Biochemical Methane Potential (BMP) Assays for Predicting and Enhancing Anaerobic Digester Performance, Agricultural and Biosystems Engineering, Iowa State University, 2009.

[21] M. Lesteur, E. Latrille, V. M. Bellon, J. M. Roger, C. Gonzalez, G. Junqua, J. P. Steyer, First step towards a fast analytical method for the determination of Biochemical Methane Potential of solid wastes by near infrared spectroscopy. Bioresource Technology. 102 (2011) 2280-2288.

[22] J. Jimenez, H. Lei, J-P. Steyer, S. Houot, D. Patureau, Methane production and fertilizing value of organic waste: Organic matter characterization for a better prediction of valorization pathways. Bioresource Technology. 241 (2017) 1012-1021.

[23] J. Yin, X. Yu, Y. Zhang, D. Shen, M. Wang, Y. Long, T. Chen, Enhancement of acidogenic fermentation for volatile fatty acid production from food waste: Effect of redox potential and inoculum, Bioresource Technology. 216 (2016) 996-1003.

[24] K. Koch, T. Lippert, J. Drewes, The role of inoculum's origin on the methane yield of different substrates in biochemical methane potential (BMP) tests, Bioresource Technology. 243 (2017) 457-463.

[25] P. Sosnowski, A. Wieczorek, S. Ledakowicz, Anaerobic co-digestion of sewage sludge and organic fraction of municipal solid wastes, Advances in Environmental Research. 7 (2003) 609-616.

[26] J. Kaźmierowicz, The effect of substrate on the amount and composition of Biogas in agricultural biogas plant, POLSKA AKADEMIA NAUK, Oddział w Krakowie. 3 (2015) 809-818.

[27] D. Deublein, A. Steinhauser, Biogas from waste and renewable resources, Wiley-Vch Verlag GmbH & Co., Weinheim, 2011.

[28] E. Głodek, L. Janecka, W. Kalinowski, A. Werszler, T. Garus, J. Kościanowski, G. Siemiątkowski, Pozyskiwanie i energetyczne wykorzystanie biogazu rolniczego. Instytut Szkła, Ceramiki, Materiałów Ogniotrwałych i Budowlanych, Oddział Inżynierii Materiałowej, Procesowej i Ochrony Środowiska w Opolu, Wydawnictwo Instytut Śląski, Opole, 2007.

[29] Z. Sadecka, S. Myszograj, M. Suchowska-Kisielewicz, A. Sieciechowicz, Substraty do procesu ko-fermentacji, Uniwersytet Zielonogórski, Zeszyty Naukowe. 150 (2013) 23-33.

[30] I. Dioha, C. Ikeme, T. Nafi'u, N. Soba, Y. M.B.S, Effect of carbon to nitrogen ratio on biogas production, International Research Journal of Natural Sciences. 1 (2013) 1-10.

[31] J. Ward, Near-Infrared Spectroscopy for Determination of the Biochemical Methane Potential: State of the Art, Chemical Engineering & Technology, 39 (2016), [watch: 02 march 2018], available in: https://onlinelibrary.wiley.com/doi/abs/10.1002/ceat.201500315.

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VERIFICATION OF A METHOD FOR DETERMINING THE LIMIT PRESSURE PEAK IN A MECHANICAL CONTINUOUSLY VARIABLE TRANSMISSION

Abstract
This research concerns the continuously variable transmission that is to be used in a hybrid drivetrain with a mechanical energy accumulator as a secondary energy source. The purpose of this research is to verify the method of determining the pressure surge which ensures a fast but safe ratio change, from the perspective of the belt slip point of a continuously variable transmission.

The obtained results allowed to decide on the design of a more extensive test bench enabling simulation of the load of a continuously variable transmission resulting from the acceleration and braking of the car's mass. In addition, the test results confirmed the possibility of regulating the pressures in two actuators to change the ratio and increase the speed of this change.

Key words
CVT, chain slip, dynamics, fuel save, hybrid drivetrain

Introduction

The upcoming environmental regulations concerning the reduction of emissions of harmful compounds contained in exhaust gases, enhance the popularity of stepless transmissions used for drive systems of passenger cars. Such a solution can also be transferred to a reduction in fuel consumption due to the possibility of operating an internal combustion engine in its optimal range due to applying the control strategy required at a given moment.

One of the ideas to meet the requirements is alternative vehicle powertrain hybridization using hybrid pneumatic powertrain. This kind of solution can be found in [1]. Another idea is using compressed air as an innovative solution for hybridization for small gasoline engine. The combination of a conventional IC engine and a pneumatic short-term storage system to achieve lower fuel consumption is described in [2]. Currently most popular solution for hybrid vehicles is hybrid electric vehicle. Electric storage in high voltage batteries with technical, economic and environmental impacts assessments is described in [3] and [4].

Another idea how to increase the overall efficiency of the drive system is to use an additional (secondary) energy source that could replace the internal combustion engine during its worst-performing periods and which would be able to accumulate lost energy for later delivery while decelerating the vehicle. Such ideas are realized by hybrid propulsion systems combined in different configurations of the primary energy source, which is most often an internal combustion engine with a secondary energy source. Electric batteries that cooperate with motors and power generators are the most frequently used secondary source of energy by car manufacturers. (More information about configurations of hybrid drive systems can be found in [5].) Regardless of the type of secondary energy source, each configuration of a hybrid system should ensure compensation of weaknesses of one source with the advantages of the other. Thanks to this, it is possible to enable both energy sources to work specifically in the areas of their greatest efficiency.

An interesting, much less complicated and cheaper alternative solution is a mechanical energy accumulator. In drive systems using electric machines, the stepless module can consist of a planetary gear (e-CVT). The most rational drive system with a mechanical energy accumulator use a mechanical continuously variable transmission. The same transmission, in mode of operation with an internal combustion engine, can serve as a gearbox. In this solution, a high speed and precise ratio change of the continuously variable transmission is required throughout its entire range.

The two main advantages of hybrid drivetrain systems are the reduction of pollutants contained in exhaust gases and reduced fuel consumption.

Another very important advantage of hybrid drivetrains equipped with a steel flywheel is that their production and recycling is cheaper and more environmentally friendly than using electric energy accumulators.

Review of solutions for hybrid drive systems

In most advertising materials, manufacturers write about the kinetic energy recovery system (KERS). In principle, each hybrid propulsion system should allow for the recovery of a car's kinetic energy during braking, however, in order to comply with the manufacturers' names, the terminology used has been preserved.

There are many solutions for hybrid drive systems. Currently, offers of hybrid car manufacturers are mainly focused on electric hybrid vehicles (HEV). Some of these have the option of recharging the battery from an external power source (plug-in hybrid electric vehicle - PHEV). The other solutions described below were used in motor sports or remained in the prototype phase.

- Hybrid Electric Vehicle by Toyota [6]

The system is composed of the electric motor, the engine, the battery, the generator, the power split device and the power control unit (inverter/boost converter/DC/DC converter). The power split device transfers part of the power produced by the engine to drive the wheels, and the rest to the generator to either provide electric power for the motors or to recharge the battery.

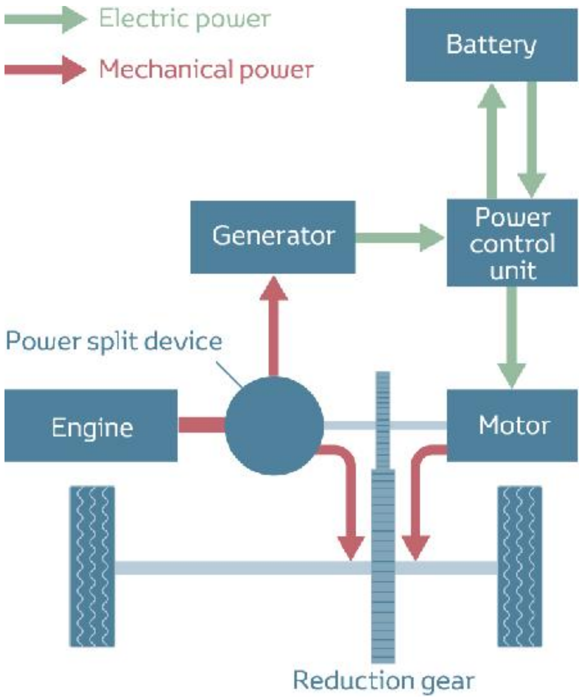

Fig. 1. Toyota Hybrid System (THS II)
Source: [6]

- Electric KERS [7]

In this solution, the electric machine is connected to the crankshaft of the engine. When braking the vehicle, part of the torque is transferred to this electric machine (operating as a power generator) that converts the vehicle's kinetic energy into electricity which is stored in batteries. During the use of stored energy, the batteries supply the electric machine which then operates in the electric motor mode and is able to transmit up to 63kW of power.

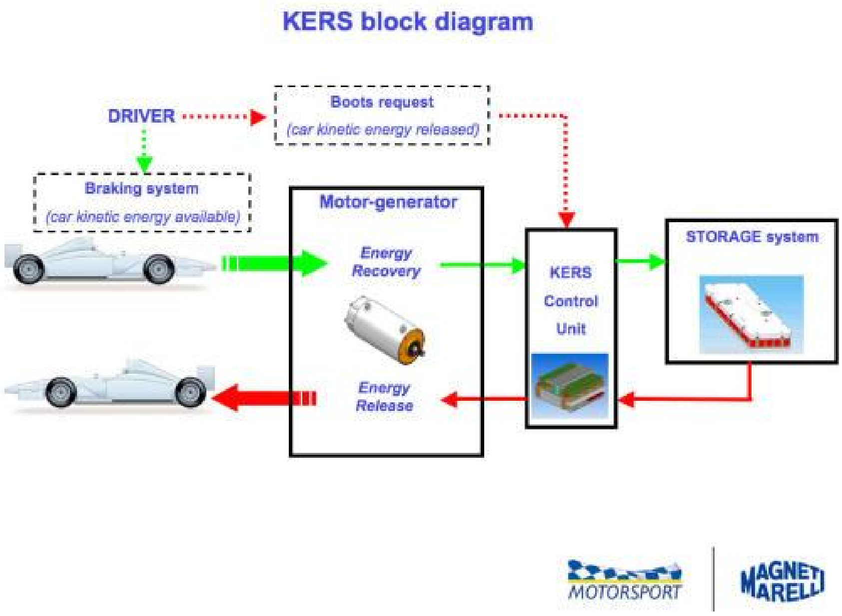

Fig. 2. Electric KERS - a solution by Magneti Marelli
Source: [7]

- Electro-mechanical KERS - Williams solution [8]

The idea behind this solution is the generation of electricity during the vehicle's braking by using electric machines operating at the moment of braking as current generators (60kW each) by being connected to the wheels of the front axle. This energy is then used to accelerate the flywheel up to 40,000 rpm, which also serves simultaneously as the rotor of the second electric machine which works at that time as an electric motor. When the demand for additional drive force arises, the roles of the two electric machines are reversed. Stored by the rotating flywheel (the rotor of the second electric machine), the energy is converted into electric energy generated by the second electric machine operating as a power generator. Then this energy goes to electrical motors connected to the front wheels.

Fig. 3. Diagram of the electro-mechanical KERS system
Source: [8]

- Mechanical KERS - Flybrid solution (Torotrak Group) [9]

In this solution, the original drive source through the conventional drive system is connected to the wheels of the front axle. The secondary energy source (carbon fiber flywheel weighing 6kg) during braking of the vehicle is driven from the rear wheels by a mechanical toroidal variable speed transmission which can even reach 60,000 rpm. Then, to transfer the accumulated energy to the wheels, the variable transmission changes the ratio in such a way as to reduce its speed so that the flywheel accelerates the car's wheels.

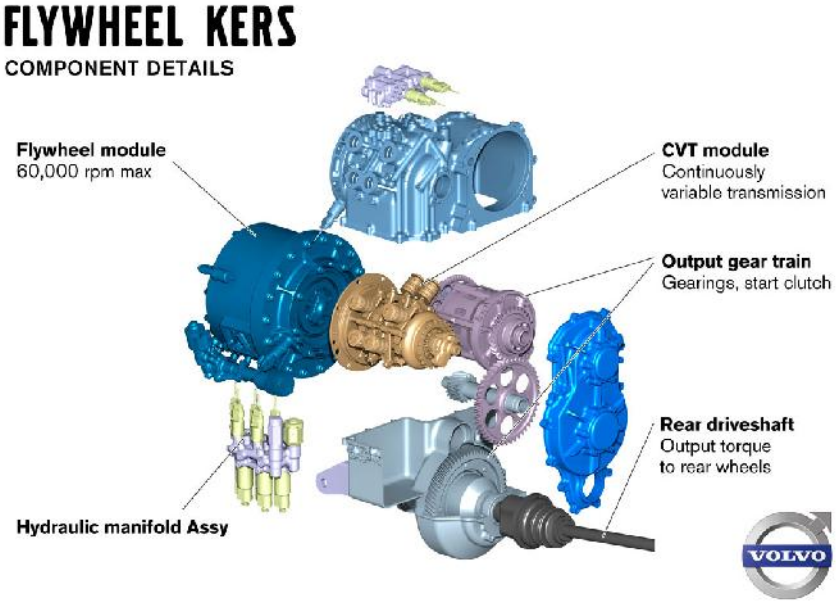

Fig. 4. Diagram of the mechanical KERS system
Source: [9]

This system was the only one designed for a passenger car intended for use in traffic. The manufacturer claims that urban traffic allows it to reduce fuel consumption by up to 25%, and according to the new European cycle, while driving the engine will be shut down for about 50% of the time.

Mechanical continuously variable transmission

The most popular type of mechanical continuously variable transmission uses a metal belt or chain. It works with two pulleys, each consisting of two cones. Moving one cone away reduces the wrap radius. At the same time a cone is moved on the second wheel to maintain constant chain or belt tension. The change in diameters changes the ratio.

Each of the mentioned solutions has devices that act as a stepless module. This can be in the form of a properly connected planetary gear, an inverter that controls the operation of electric motors and generators or a mechanical continuously variable transmission.

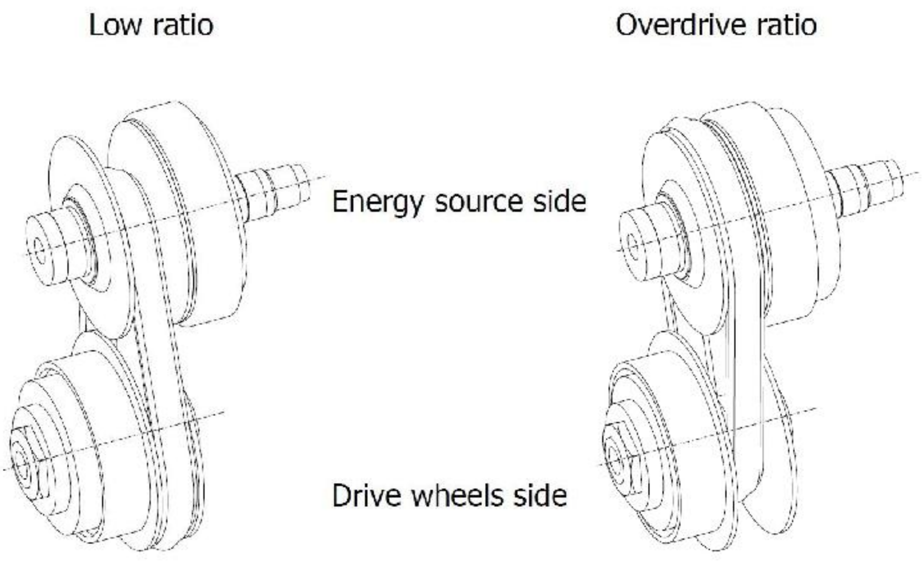

Fig. 5. Mechanical belt/chain continuously variable transmission
Source: Author's

Prototype hybrid drivetrain

The purpose of this research was to verify the method of determining the pressure surge which ensures a fast but safe ratio change, from the perspective of the belt slip point of a continuously variable transmission.
Designed mechanical energy accumulator should allow to accumulate energy allowing to achieve speed of 50km/h by 1000kg car without using internal combustion engine.

The proposed prototype hybrid drive system assumes the use of a mechanical continuously variable transmission using the LuK chain. This transmission acts as a gearbox when using the primary energy source and as a stepless module connecting the mechanical energy accumulator with the drive wheels of the car.

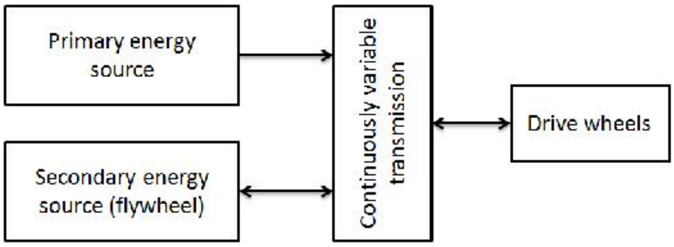

Fig. 6. The general scheme of the prototype hybrid drive system
Source: Author's

The purpose of using a mechanical energy accumulator is to accumulate the kinetic energy of the decelerating vehicle in order to use it during acceleration. When decelerating the vehicle the energy must be transferred from the diminishing speed of the car to an ever faster-spinning flywheel. The necessity of changing the ratio between the wheels of the vehicle and the flywheel follows in a continuous manner. This is similar when accelerating the vehicle. The process of charging and discharging the mechanical accumulator requires the transmission to change ratio continuously during the braking or acceleration of the car, which is significantly shorter than the ratio change required by a stepless conventional drive system. The function of the stepless change is fulfilled by sliding conical discs coupled with a chain. The displacement of the discs is carried out by hydraulic cylinders with the same areas. Correct flow and oil pressure in the cylinders are to ensure the specified ratio and chain tension sufficient to transfer the torque. This tension must ensure that the chain does not slip excessively, but it should not be too large so as to increase the mechanical losses of the transmission. More information about slip control can be found in [10].

In a situation in which the pressure P1 and P2 are constant, the ratio is fixed and there is no chain slip, the change of any of the pressures will change the ratio and change the chain tension force. In the prototype transmission, the stops of the mechanical stoppers of the conical wheels were placed on a pulley located on the side of the energy source. For this reason, the secondary pulley is treated as responsible for the belt tension because this wheel will not lean against the mechanical limiter and will be affected by the force resulting from the oil pressure. Consequently, the input pulley is generally considered to be responsible for the transition. For this reason, in the tests of the continuously variable transmissions, the pressure P2 is most often set constant, changing the ratio by pressure P1 [11].

In the situation of starting from the set operating conditions, to change the ratio at constant pressure P2, the pressure P1 should be changed. The greater the pressure change will be, the faster the change speed will be. The problem is the situation when pressure P1 is close to the extreme, the difference between initial and set pressure which determine ratio speed change is limited. In this case, stability of P2 pressure can be dispensed and this pressure used to change the ratio. This situation is shown in Figure 7.

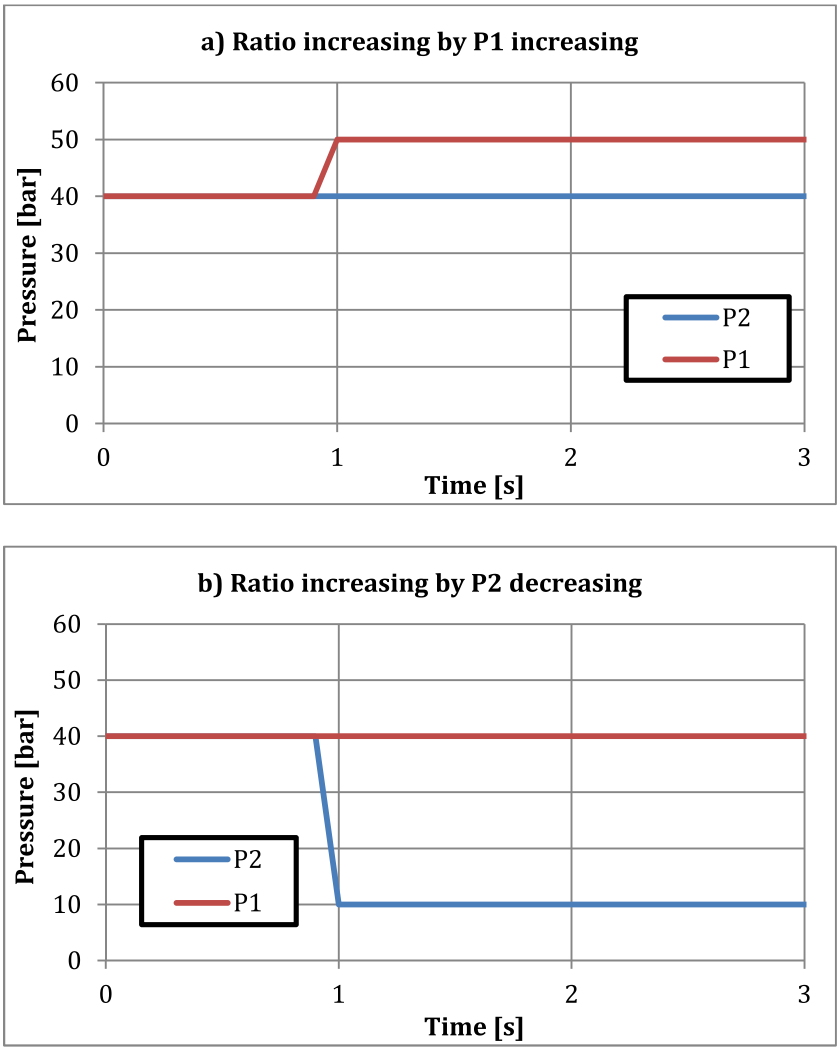

Fig. 7. Increasing the ratio by a) increasing P1; b) decreasing P2
Source: Author's

In the situation presented in diagram 7b), the pressure difference that can be obtained in relation to the steady state, causing the ratio to increase is much higher (30bar) than in the situation shown in diagram 7a), where the pressure difference with respect to the steady state is much lower (10bar). It follows from the above that in such a case the terms "constant pressure actuator" and "variable pressure actuator" should not be assigned to specific actuators. However, a problem arises as to how to prevent the chain from slipping. The difficulty in determining the analytical equation providing the required chain pressure in transient states showed the necessity to perform tests at the test bench enabling simulation of the inertia of a car. Such a test bench is under construction, and for the purpose of preliminary research, initial tests were carried out on the existing test bench. Different control problems are described in [12].

Load of continuously variable transmission

The load of the continuously variable transmission during cooperation with the secondary energy source in the prototype hybrid drive system results from the energy exchange between the car and the mechanical energy accumulator. During energy recuperation, the torque loading the transmission results from increasing the flywheel rotational speed at the expense of reducing the speed of the car. In the return process when force is accumulated in the energy wheel, the load on the transmission results from the increase of the speed of the car at the expense of reducing the rotational speed of the flywheel. These phenomena result from the second principle of Newton's dynamics. Allowing the chain to slip causes damage to the pulleys and chain which can lead to difficulties in setting and maintaining the set ratio.

Test bench

Figure 8 shows the diagram of mechanical, hydraulic and electrical connections located on the test bench.

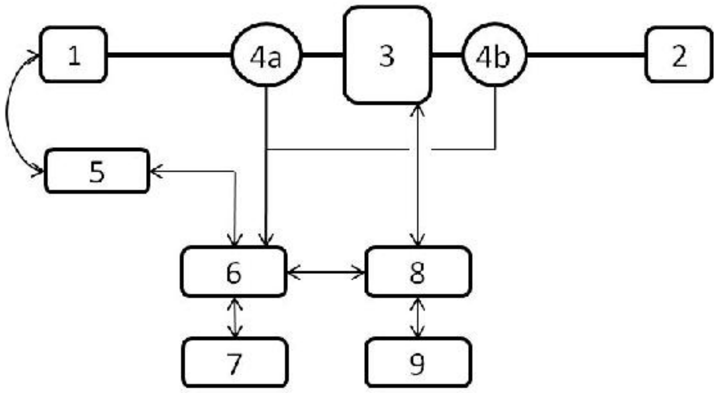

Fig. 8. Scheme of the test bench: 1-electric motor; 2-inertia; 3-continuously variable transmission; 4a, 4b-torquemeters; 5-inverter; 6-ECU; 7-operator interface; 8-hydraulic blocks; 9-hydraulic group

Source: Author's

An electric machine (motor) (1) was used to drive the tested variable transmission (3). By using the inverter (5) it was possible to smoothly control the engine speed in a range of ±3000rpm. (More information about the electric motor control system used in the test bench can be found in [10].) The load element of the transmission was a rotating mass (2) with moment of inertia I = 0.6 kgm2. Two torque gauges (4a and 4b) were used to measure the torque at the input and output of the tested transmission. For lubrication and for controlling the pressures in the pulley cylinders an external hydraulic group (9) was used with the drive source independent of the work of the tested object. This group supplied hydraulic blocks (control with preliminary pressure [13]) (8) enabling a smooth change of pressure (and thus a change in transmission ratio and belt/chain tension. This system worked in a closed loop of pressure control. Using the user interface (7), the operator controlled the control platform (6). Thanks to this, it was possible to set and read data.

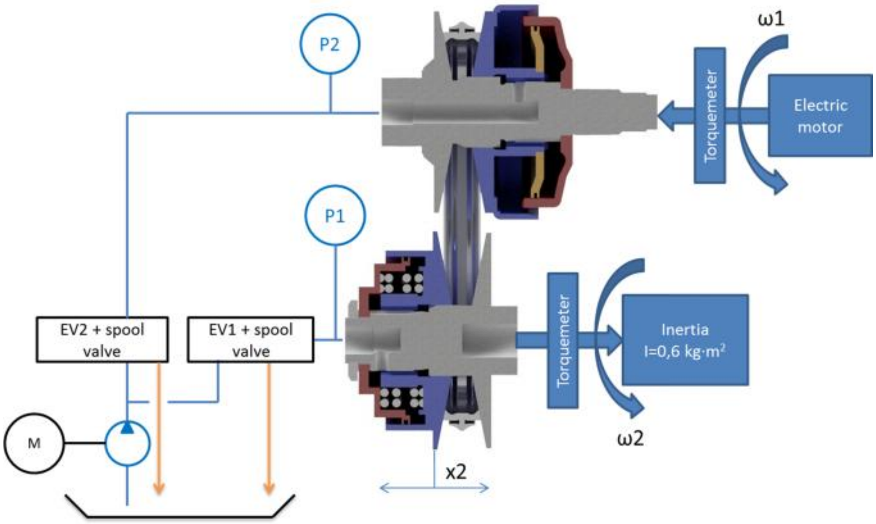

Fig. 9. Diagram of connection of the tested transmission to the hydraulic system and the drive and braking unit

Source: Author's

During the tests, the electric machine was controlled in the rotational speed mode, set at a constant value of n=2000 rpm. The transmission ratio of the continuously variable transmission was calculated based on the indication of the speed sensors of the rotating pulleys as the quotient of the rotational speed of the output pulley and the input pulley:

$I_{cvt} = \frac{\omega_2}{\omega_1}$.

In addition, during the tests, the position of the moving cone of the output pulley was checked, which was converted into a ratio resulting from the radius of the belt. Comparison of these two ratios allowed for the occurrence of chain slip.

Research

The aim of the conducted research was to check the methodology for determining the maximum possible speed of transmission shifting of a continuously variable transmission linked to hybrid drive system's road wheels with a mechanical energy accumulator. This consisted of establishing one pressure at a constant level and setting the second pressure with a value ensuring the given ratio and causing a sudden change in that pressure. A given series of measurements started with small changes in pressure and ended at the time when symptoms appeared indicating slip occurrence. The first attempts were to establish the pressure in the secondary pulley actuator - P2.

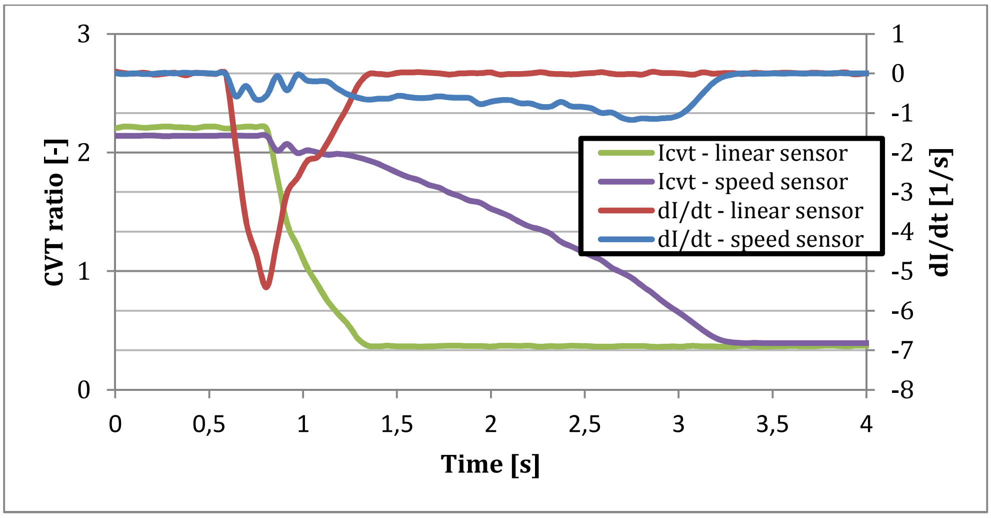

Fig. 10. Sample result from a constant P2 pressure test

Source: Author's

Figure 10 shows sample results from a constant pressure test P2 = 35bar. For a given jump ΔP1 = 17bar there was a slip of the belt - this is indicated by a different course of the ratio curve resulting from the position of the cone wheel than the ratio curve calculated from the pulleys speed sensors and the accompanying metallic noise coming from the tested body. Subsequent tests assumed maintaining constant pressure in the primary pulley cylinder.

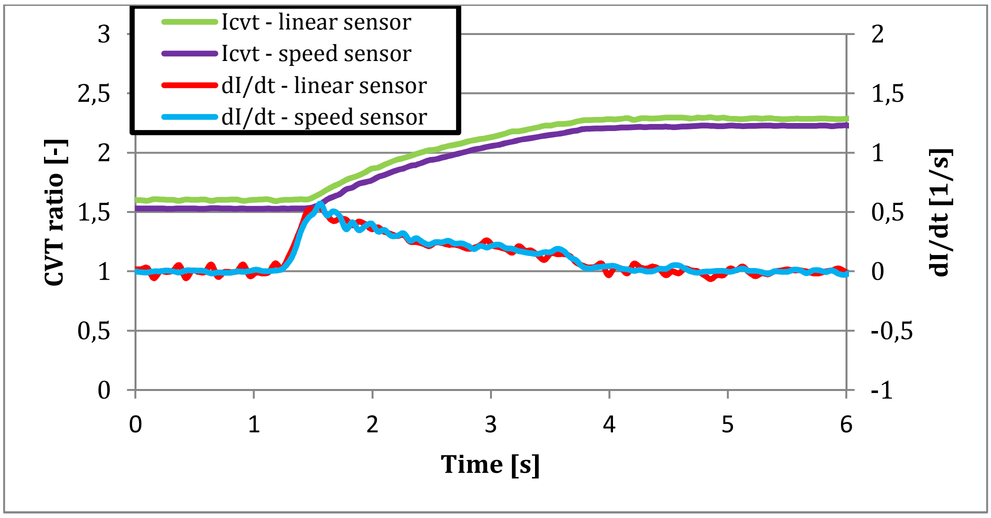

Fig. 11. Sample result from a constant P1 pressure test

Source: Author's

Figure 11 shows an example of the results from a test performed at a constant pressure of P1 = 35bar. In this case, the coverage of the ratio curves indicates the absence of chain slip (ΔP2 = 10bar).

Results

Figure 12 shows limit values of pressure changes that cause ratio change without the risk of chain slippage that could damage the transmission.

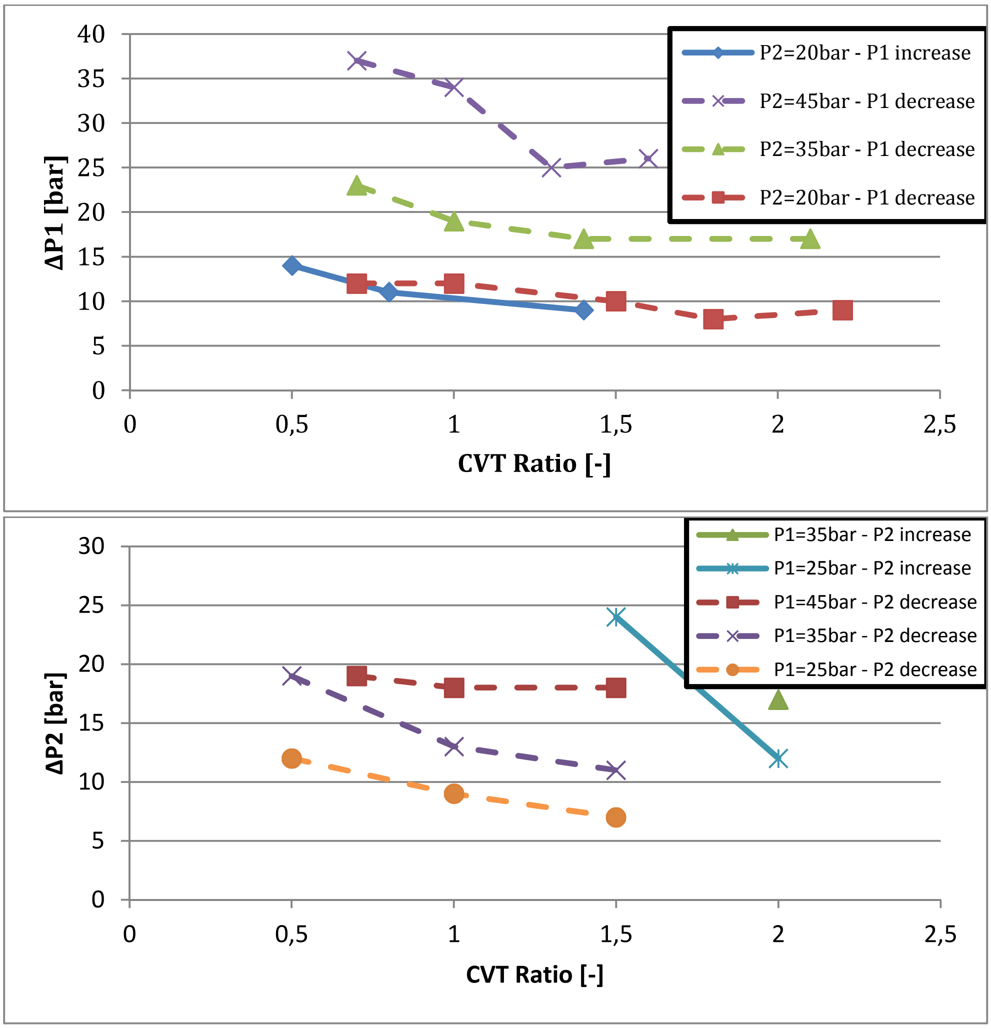

Fig. 12. Limit ΔP1 and ΔP2 values ensuring no chain slip
Source: Author's

For pressures P2 = 35bar and P2 = 45bar, during the P1 pressure increase (increase of the ratio), excessive chain slip was not present, so for this case limit values of ΔP1 are 9-15bar for P1 increasing and 9-36bar for P1 decreasing. Higher ΔP1 values correspond to higher P2 values. Only at pressure P1 = 20bar there were chain slip. This is due to the large difference in pressure possible to achieve. For pressure P1 = 45bar, no occurrence of slip was noticed when increasing pressure P2.

Summary and conclusions

The tests clearly indicated that a greater pressure jump in relation to its steady state value translates into a higher rate of shifting. However, this does not mean that in each case the pressure can be increased or decreased in steps up to the extreme values (0 or 50bar) as this may lead to chain slip. The solution to this problem could be simultaneous control of both P1 and P2 pressure. The introduction of such a solution would require the implementation of a complicated algorithm that would take in account the dynamic changes in chain contact and radii. The performed tests confirmed the correctness of the test methodology, which will be carried out on a test stand which will enable simulation of the load of the variable transmission resulting from braking and acceleration of both the car and the mechanical energy accumulator. This test bench is currently being built at the Department of Vehicles and Machine Building Basics of the Lodz University of Technology.

Higher drive comfort, reduction of harmful emission compounds contained in exhaust gases and reduction of fuel consumption are compelling reasons for the search for newer and more advanced solutions in the field of hybrid vehicles.

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References

[1] Z. Dimitrova, P Lourdais, F. Maréchal, Performance and economic optimization of an organic rankine cycle for a gasoline hybrid pneumatic powertrain, Energy 86 (2015) 574-588.

[2]] Z. Dimitrova, F. Maréchal, Gasoline hybrid pneumatic engine for efficient vehicle powertrain hybridization, Applied Energy 151 (2015) 168-177.

[3] Z. Dimitrova, F. Maréchal, Environomic design of vehicle energy systems for optimal mobility service, Energy 76 (2014) 1019-1028.

[4] Z. Dimitrova, F. Maréchal, Techno–economic design of hybrid electric vehicles and possibilities of the multi-objective optimization structure, Applied Energy 161 (2016) 746-759.

[5] BOSCH, Napędy hybrydowe, ogniwa paliwowe i paliwa alternatywne (hybrid drives, fuel cells and alternative fuel), Wydawnictwa Komunikacji i Łączności, Warszawa, 2010.

[6] http://www.toyota-global.com/innovation/environmental_technology/technology_file/hybrid/hybridsystem.html access 1.05.2018

[7] http://www.racecar-engineering.com/articles/f1/kers-in-f1-how-kers-will-change-formula-one-in-2011/ access 1.05.2018

[8] http://www.greencarcongress.com/2010/02/gt3r-20100211.html access 1.05.2018

[9] https://www.autoevolution.com/news/torotrak-to-supply-parts-for-volvo-s-flywheel-kers-35977.html access 1.05.2018

[10] Z. Pawelski, Falowniki ABB + moc krążąca = oszczędność energii na stanowisku badawczym (ABB + circulating power = energy saving on a test bench), Napędy i Sterowanie, 4 (2005) 14-16.

[11] B. Radzymiński, J. Goszczak, Generating the pressure to control the gear ratio of a continuously variable transmission in car, The Archives of Automotive Engineering, 74 (2016) 95-104.

[12] B. Radzymiński, Some control problems of continuously variable belt transmission, IOP Conference Series: Materials Science and Engineering, 148 (2016) 012049.

[13] BOSCH, Elektroniczne sterowanie skrzynką biegów EGS (Electronic control of the EGS gearbox), Wydawnictwa Komunikacji i Łączności, Warszawa, 2005.