ISSN 2300-5599

ACTA INNOVATIONS

CENTRUM
BADAŃ I INNOWACJI
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RESEARCH AND INNOVATION CENTRE

no. 18

January 2016

Acta Innovations

quarterly

no. 18

Konstantynów Łódzki, Poland, January 2016

ISSN 2300-5599

Original version: online journal

Online open access: www.proakademia.eu/en/acta-innovations

Articles published in this journal are peer-reviewed

Publisher:

Research and Innovation Centre Pro-Akademia

9/11 Innowacyjna Street

95-050 Konstantynów Łódzki

Poland

ACTA INNOVATIONS

no. 18

January 2016

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AN ANALYSIS OF THERMO-MAGNETIC CONVECTION OF PARAMAGNETIC FLUID IN RECTANGULAR ENCLOSURE

Abstract

The thermo-magnetic convection of paramagnetic fluid in a strong magnetic field is studied. The fluid is aqueous solution of glycerol with gadolinium nitrate hexahydrate. Experimental enclosure – rectangular vessel with aspect ratio equal to 2 – was heated from the bottom, and cooled from the top. Temperature difference between top and bottom walls was kept constant ΔT=5K. The magnetic induction was increased stepwise from 1 to 10 [T]. On the basis of temperature measurements, analysis of heat transfer and fluid flow were performed, showing that magnetic field strongly enhance heat transfer (over 300%) and that aspect ratio of the enclosure has a great influence on heat exchange in the system.

Key words

thermo-magnetic convection, strong magnetic field, experimental analysis, paramagnetic fluid

Introduction

Natural convection processes include tremendous number of situations in industrial, astrophysical and environmental applications. In all cases, controlling convection processes is a very important aspect. However, before concepts for convection control can be applied to real systems, they need to be studied fundamentally and experimentally. Fluids, in terms of magnetic properties, can be characterized as follows: diamagnetics (i.e. water), paramagnetics (i.e. air) and ferromagnetics (i.e. cobalt, nickel, iron), and so one of the ways to control natural convection is by applying a strong magnetic field to the system. Due to technological progress, it became possible to build strong superconducting magnets with relatively low costs which allowed to study the influence of strong magnetic field on non-ferromagnetic fluids. Ever since, enhancement or suppression of convection phenomena with strong magnetic field, and so the betterment of heat and mass transfer, have been a research topic for many researchers. In 1991 Braithawaite [1] used the magnetic field to both enhance and suppress the Rayleigh-Benard convection in a paramagnetic solution, and showed that the effect depends on the orientation of the magnetic force and temperature gradient. Tagawa [2] developed a simple model equation to thermo-magnetic convection. Bednarz [3] studied numerically and experimentally the influence of the magnetic field on a convection processes in a system with one side wall heated, and the opposite one cooled. Fornalik [4] studied effects of magnetic field influence on natural convection in thermosyphon-like configurations. Pyrda [5] studied thermo-magnetic convection in transient and turbulent flow regimes. Also, new studies are carried out in the field concerning use of nanofluids as magnetic fluids [6]. Phenomena related to the magnetic field and its effect on convection processes have found applications in biology [7], chemistry [8], [9], medicine [10], [11] and engineering [12]–[14].

Turan [15] performed two-dimensional simulations of laminar natural convection in systems with different aspect ratios (AR=height/width) and concluded that aspect ratio is a very important parameter in heat transfer analysis. But in the literature there is no available experimental data about the influence of experimental enclosure aspect ratios on thermo-magnetic convection. Considering that Authors have access to a superconducting magnet (up to 10T) and that efficient heat exchange corresponds to lower costs, Authors took on the challenge of testing the effect of the enclosure AR on thermo-magnetic convection and heat transfer. Obtained results can be used as a first step in development of cooling technologies utilizing magnetic field influence on the heat transfer.

Experimental set-up

The experimental apparatus is shown in Fig.1. and was composed of five elements: two copper plates (one for the cooled top, second one for the heated bottom), a rectangular cavity made from Plexiglas, and cooling and heating chambers. The rectangular cavity, of dimensions height d=64mm, width a=32mm, had six holes, where six T-type thermocouples was inserted. The bottom copper plate was heated with nichrome wire connected to a DC power supply. The electric voltage and current of the nichrome wire were measured with a multi-meter. Top plate was cooled by cold water running from a thermostat. Temperature of heated and cooled copper plates was measured with six T-type thermocouples inserted into small holes in each plate. The experimental apparatus was positioned in the superconducting helium free magnet shown in Fig. 2. (HF10-100VHT-B, *Sumito Heavy Industries,* Ltd. Japan), which can generate magnetic induction up to 10 T. The position of the enclosure along the magnet axis was chosen in the upper half of the bore, where the gravitational and magnetization forces acted in the same direction, causing enhancement of the heat and mass transfer, shown in Fig. 3.

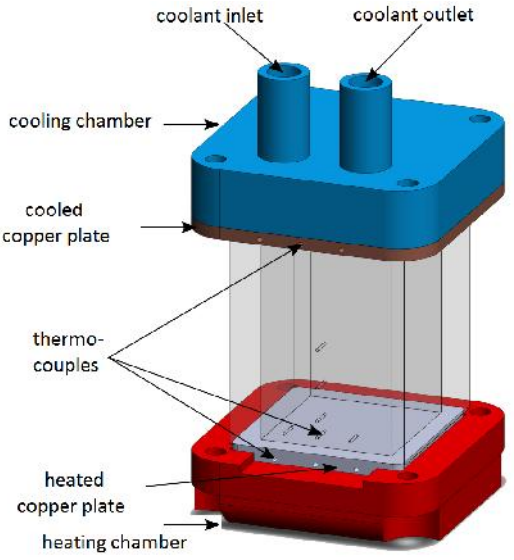


Fig. 1. Experimental enclosure
Source: Author's

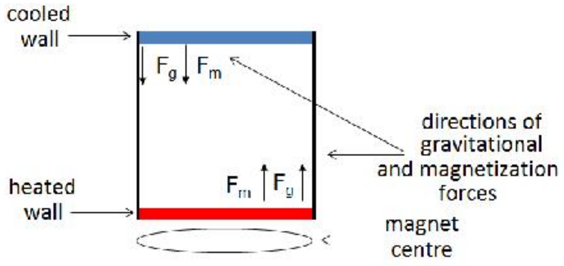


Fig. 3. Directions of gravitational and magnetization forces
Source: Author's

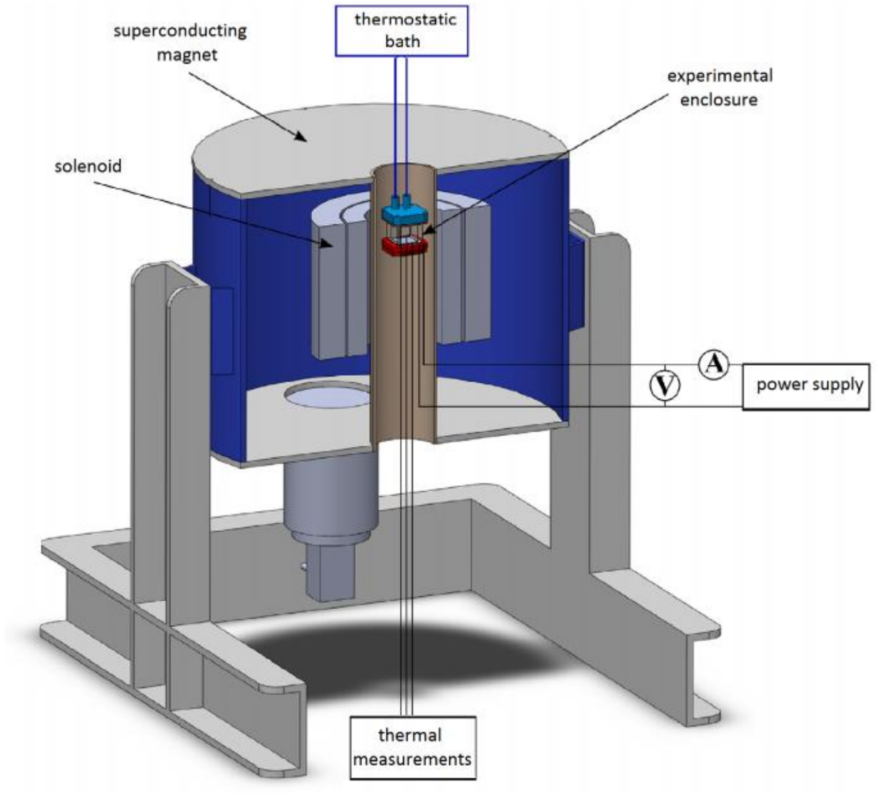


Fig. 2. Experimental setup and location of a rectangular enclosure in the magnet
Source: [5]

The enclosure was filled with 50% volume aqueous solution of glycerol with the addition of 0,8 mol/(kg of solution) gadolinium nitrate hexahydrate ($Gd(NO_3)_3 \cdot 6H_2O$) to make it paramagnetic. In literature there are research publications concerning the effect of a strong magnetic field on thermo-magnetic convection for systems which aspect ratio equal 1. The fluid for following studies was selected as observed in [5], which gave an opportunity to compare obtained results.

Necessary properties of the fluid were measured: viscosity using Ubbelohde viscometer, density with a pycnometer, magnetic susceptibility with magnetic susceptibility balance by Evan's method. Other properties were taken from [5]. All of the necessary properties are listed in Table 1.

Table 1. Properties of the working fluid at 298 K

Properties	Symbol	Value	Unit
Density	ρ	1418,1	kg/m^3
Dynamic viscosity	μ	$1{,}56\cdot10^{-2}$	kg/m·s
Kinematic viscosity	ν	$1{,}10\cdot10^{-5}$	m^2/s
Thermal conductivity	λ	0,376	W/m^2·K
Thermal expansion coefficient	β	$4{,}13\cdot10^{-6}$	1/K
Thermal diffusivity	a	$7{,}55\cdot10^{-8}$	m^2/s
Heat capacity	c_p	$2{,}92\cdot10^{3}$	J/kg·K
Mass magnetic susceptibility	χ_m	$2{,}58\cdot10^{-7}$	m^3/kg
Magnetic susceptibility	χ	$3{,}41\cdot10^{-4}$	-
Prandtl number	Pr	146	-

Source: Author's

Experimental procedure

Experimental procedures were started by estimating heat losses in the system. This was done by placing the enclosure, filled with water, at the predetermined position, but the vessel was rotated 180 degrees, so the cooled wall was at the bottom, and the heated one at the top. Such placement allowed to reach the conductive state in the system (stratification), with no fluid movement. After setting the temperature difference between top and bottom wall and waiting sufficiently long for the system to stabilize, linear temperature distribution was achieved and heating power was measured. Assuming a one-dimensional conductive heat flow in the fluid (with no fluid movement), the heat flux can be calculated from the Fourier's law. Thus, the difference between directly measured heat flux on the heated wall and heat flux calculated from Fourier's law is the heat loss in the system, which is presented in Fig. 4.

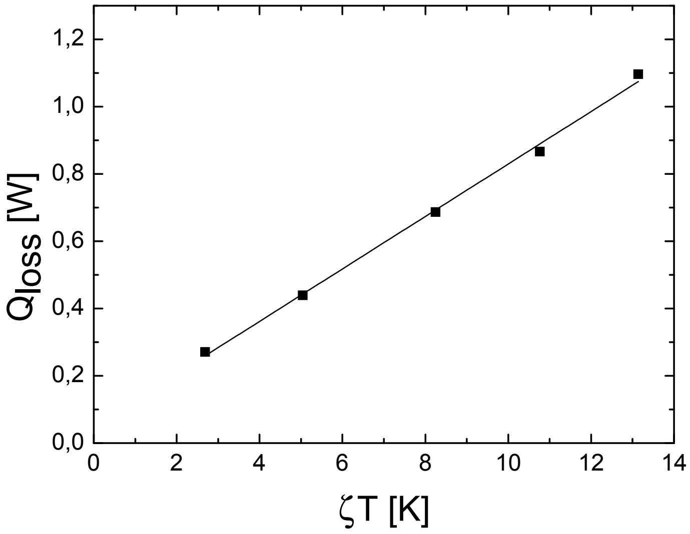


Fig. 4. Heat loss at several temperature differences
Source: Author's

Then main experiment was conducted. With enclosure filled with paramagnetic fluid and positioned with the bottom wall heated, the power supply was set to obtain chosen temperature difference between top and bottom walls (~ΔT=5K). The enclosure was left to acquire the stable state. After this was achieved, temperature, electric current and voltage were recorded. Then, magnetic field was applied to the system by stages of 1 T, from 1 up to 10 T. At each step, the electric current and voltage had to be corrected to keep constant temperature, and the system had to reach stable state. As previously, after thermal stabilization was obtained, temperature signal was recorded.

Flow structure analysis

In the analysis of turbulent transport mechanisms a very useful tool is a spectral analysis of a scalar field. With an assumption that the turbulence is homogenous, spectral functions can be calculated with the utilization of Fast Fourier Transform (FFT). In general, temperature spectral functions depend on the energy dissipation, thermal diffusivity, kinematic viscosity and temperature. But in some ranges, spectral function does not depend on the diffusion, and so does not rely on kinematic viscosity and thermal diffusivity. This range is called inertial-convective [16] and the spectral function has an inclination of wave number with -5/3 exponent. In cases when thermal diffusivity becomes more significant, the spectral function has an inclination of reverse wave number, and this range is called viscous-diffusive [16].

Heat transfer analysis

A criterion speaking of heat transfer in the system is a dimensionless Nusselt number, which can be written as follows:

$$Nu\,\mathrm{X}\frac{\dot{Q}_{net\_conv}}{\dot{Q}_{net\_cond}} \tag{1}$$

The net conduction (Q_{net_cond}) and net convection (Q_{net_conv}) heat fluxes were estimated by the method proposed by Churchill and Ozoe [17], which is based on following formulas:

$$\dot{Q}_{net\_cond}\,\mathrm{X}\dot{Q}_{cond}\,\mathrm{Z}\dot{Q}_{loss} \tag{2}$$

$$\dot{Q}_{net\_conv}\,\mathrm{X}\dot{Q}_{conv}\,\mathrm{Z}\dot{Q}_{loss} \tag{3}$$

As previously said, it was assumed that the heat loss depends only on the temperature of the heated wall. As a first step to estimate the Nusselt number, conduction measurements were made. The heat losses were estimated from:

$$\dot{Q}_{loss}\,\mathrm{X}\dot{Q}_{cond}\,\mathrm{Z}\dot{Q}_{Fourier's\_law} \tag{4}$$

where

$$\dot{Q}_{Fourier's\_law}\,\mathrm{X}a^{2}\,\mathrm{a}\,\zeta T/d \tag{5}$$

- d - enclosure height 0,064 [m];
- a – enclosure width 0,032 [m];
- λ – thermal conductivity of the fluid [$W/m^2 \cdot K$]
- ΔT – temperature difference between heated and cooled walls [K].

Heat flux was calculated for conduction area of 0,032m x 0,032m. The estimated heat loss was approximated linearly:

$$\dot{Q}_{loss}\ X 0,0831\ \zeta T \qquad (6)$$

Applying equations 2, 4 and 5 to equation 1, Nusselt number can be written as:

$$Nu\ X \frac{\dot{Q}_{conv}\ Z \dot{Q}_{loss}}{d\, ^{a} \zeta T} \qquad (7)$$

The convection heat flux (Q_{conv}) is given by the product of current and voltage of the heater supply. The results of determined Nusselt number are presented in Fig. 5.

a) b)

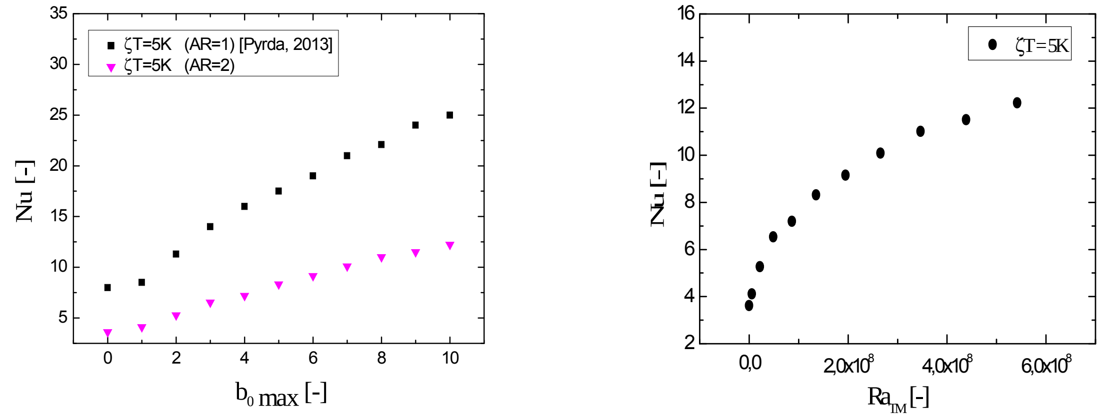


Fig. 5. The Nusselt number versus a) the magnetic induction, b) thermo-magnetic Rayleigh number

Source: Author's, [5]

Results and discussion

The results of heat transfer analysis are presented in Fig. 5. a). The Nusselt number versus thermo-magnetic Rayleigh number is shown in Fig.5.b). Thermo-magnetic Rayleigh number is defined as follows:

$$Ra_{TM}\ X Ra_T\ \Gamma Ra_M \qquad (8)$$

where:

- Ra_T is thermal Rayleigh number:

$$Ra\ X \frac{g\ \ (T_h Z T_c)\, d^3}{a\neg} \qquad (9)$$

- Ra_M is magnetic Rayleigh number:

$$Ra_M\ X(1\Gamma \frac{1}{T_0})(\frac{g¥\ \ (T_H Z T_C)\, d^3}{2a\neg}) \qquad (10)$$

- where γ is magnetization number:

$$¥\ X \frac{i\, |b_0|^2_{max}}{°«_m g d} \qquad (11)$$

and: g – gravitation acceleration, β – thermal expansion coefficient, μ_m – vacuum magnetic permeability, ν – kinematic viscosity, ρ – density, χ – magnetic susceptibility, d – characteristic dimension, a – thermal diffusivity, T_H – temperature at the heated wall, T_C – temperature at the cooled wall, T_0 – reference temperature, b_0 – magnetic induction.

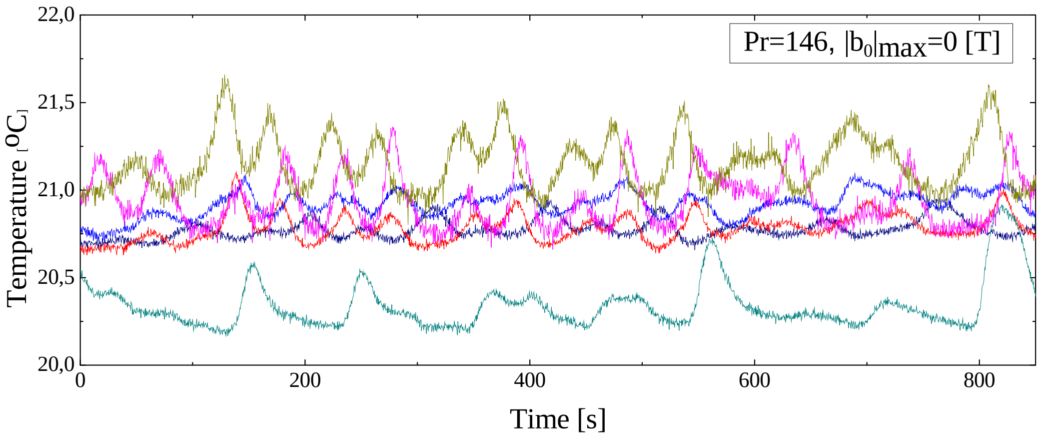
Obtained results are for the enclosure with aspect ratio equal two. The Nusselt number, at the natural convection case (without magnetic induction) was about ~3,6 for $Ra_{TM}=4\cdot10^4$. Changing the value of magnetic induction from 1 T, up to 10 T caused an increase of Nusselt number to 12,23 at 10T for $Ra_{TM}=5,4\cdot10^8$. Comparing those results with data available in literature for the same fluid but cubical enclosure with aspect ratio one, it can be seen that for the higher enclosure, heat transfer has smaller values. In the system with AR=2, total increase od Nusselt number, with magnetic induction from 0 to 10T, was about 340%, while in the enclosure with AR=1, total increase of Nusselt number was over 420%. It can be easily explained with the characteristic dimension, which plays a major role in the Nusselt number formula - because of a longer distance between heated and cooled walls, the rate of heat transfer is smaller.

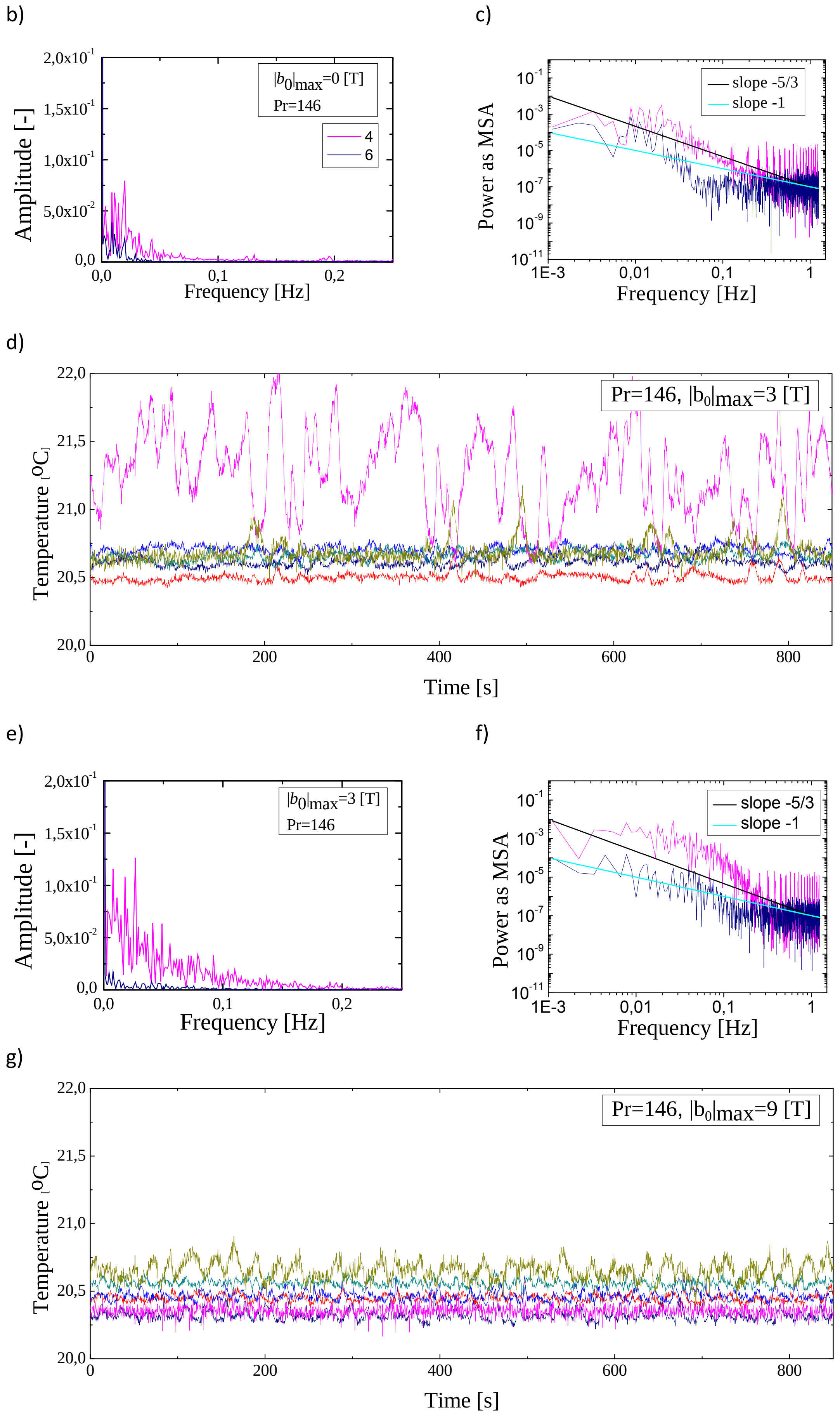
Results of temperature signal analysis are presented in Fig. 6. Spectral analysis was conducted for signals from two thermocouples, located in bottom corners of the experimental enclosure. Fig.6. a), d) and g) presents temperature changes during 15-minute measurement. In the natural convection case (b_0=0 T) and in the case of magnetic induction b_0=3 T temperature slowly fluctuates, with relatively high amplitude, while in the case of 9T temperature fluctuations have much lower amplitude. It can be concluded that magnetic field applied to the system acts to fasten the fluid flow. In higher values of magnetic induction temperature field is more uniform.

Fig. 6. b), e) and h) presents amplitude versus frequency, where characteristic peaks can be seen. For convective steady flow such peaks could be an evidence of vertical structure rotating in the enclosure with specified frequency. Because there is no particular frequency repeating in all cases, this can indicates that there were many vortexes in the fluid flow.

Fig. 6. c), f) and i). presents power spectrum as MSA (mean square amplitude) versus frequency in logarithmic scale. Blue and black lines represents slopes of wave number powers -5/3 and -1. In the case of natural convection it can be seen that black line fits the power spectrum of one thermocouple. This indicates that the flow was in inertial-convective regime. Increasing magnetic induction changed the power spectrum characteristics, as shown in Fig.6. f) and i). Spectral analysis of the signal in magnetic field equal 9 T shows quite good match to -1 slope, which is viscous-diffusive regime. This speaks of the fact, that magnetic field changes the order of the flow.

a)




b)
Amplitude [-]
2,0x10^{-1}
1,5x10^{-1}
1,0x10^{-1}
5,0x10^{-2}
0,0
0,0
0,1
0,2
Frequency [Hz]
$|b_0|_{max}$=0 [T]
Pr=146
4
6
c)
Power as MSA
10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-9}
10^{-11}
1E-3
0,01
0,1
1
Frequency [Hz]
slope -5/3
slope -1
d)
Temperature [^{o}C]
22,0
21,5
21,0
20,5
20,0
0
200
400
600
800
Time [s]
Pr=146, $|b_0|_{max}$=3 [T]
e)
Amplitude [-]
2,0x10^{-1}
1,5x10^{-1}
1,0x10^{-1}
5,0x10^{-2}
0,0
0,0
0,1
0,2
Frequency [Hz]
$|b_0|_{max}$=3 [T]
Pr=146
f)
Power as MSA
10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-9}
10^{-11}
1E-3
0,01
0,1
1
Frequency [Hz]
slope -5/3
slope -1
g)
Temperature [^{o}C]
22,0
21,5
21,0
20,5
20,0
0
200
400
600
800
Time [s]
Pr=146, $|b_0|_{max}$=9 [T]

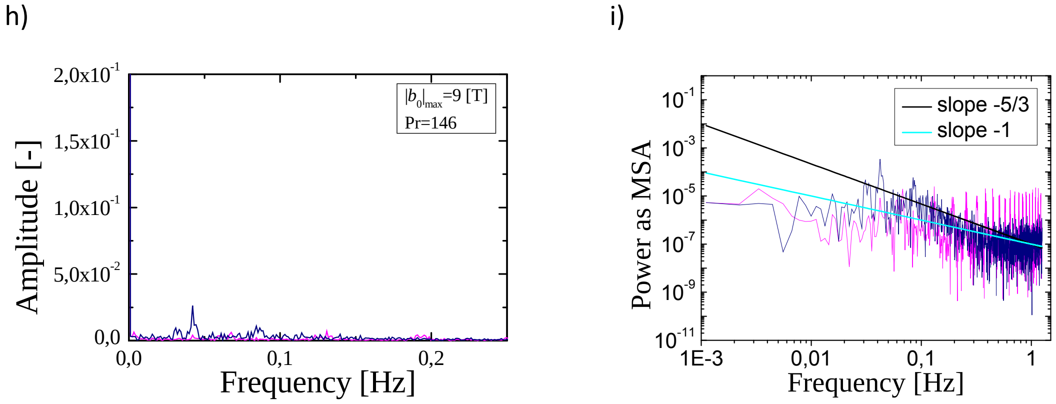


Fig. 6 a), d), g) temperature versus time series fot b_0=0,3,9 T; b), e), h) amplitude versus frequency for b_0=0,3,9 T; c) ,f), i) power spectrum versus frequency for b_0=0,3,9 T.
Source: Author's

Summary and conclusions

In this article the experimental analysis of the influence of a strong magnetic field on thermo-magnetic fluid convection was presented. Estimation of heat transfer and characteristic of fluid flow was able due to obtained temperature signal. Performed analysis leads to following conclusions:

- magnetic field strongly enhance heat transfer,
- use of magnetic field leads to enhancement of heat transfer over 300%,
- experimental enclosure height has a great influence on heat exchange in the system,
- enclosures with higher aspect ratios are characterized by smaller Nusselt numbers than enclosures with smaller aspect ratios;
- magnetic field heavily influence character of a fluid flow,
- Fast Fourier analysis is a helpful tool to characterize the fluid flow structure,
- positive reaction of the analyzed system to the magnetic field in the field of heat transfer shows a great potential in heat transfer area.

Performed studies have fundamental character, which means that the main aim is to acquire knowledge of the process mechanism, but on the basis of obtained results and conclusions, thermo-magnetic convection could be successfully used in modern cooling systems, resulting in improved heat exchange (heat dissipation), thus reducing some of the costs. In future studies Authors will determine the influence of external magnetic field on natural convection in systems with AR=0,5 and an analysis of systems, where thermally active walls are side walls.

Acknowledgements

The present work was supported by the Polish Ministry of Science (Grant AGH No. 15.11.210.306).

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TREATMENT OF SEWAGE SLUDGE FOR FUEL CELLS SUPPLY

Abstract

Sewage sludge represents the main fraction of municipal waste generated in Poland. Since its production increases rapidly, an effective method for its decomposition needs to be found. Due to conventional energy sources depletion, new solutions allowing for renewable energy production are recommended. One of the methods for conversion of sewage sludge into green energy is application of the fuel cells feeding with gaseous residuals of sewage sludge, obtained as a result of different thermal or biological processes. Such a system can be easily modified and adjusted to the individual needs, which makes this solution very promising. The article analyses biological and thermal processes that can be used in converting sewage sludge into a useful input for various types of fuel cells.

Key words

Sewage sludge, fuel cells, hydrogen, energy

Introduction

In 2010 sewage sludge production in Poland was about 520 000 tDS/a, and the most popular way for its utilization was deposition on the landfills [1]. This trend seems to be observed today, with the huge and significantly increasing sewage sludge quantities. In a few months Poland will face the real problem connected with the new legislation. As a result of the Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste [2], deposition of sewage sludge directly on landfills is prohibited. In Poland it will have to be applied starting from January 1st, 2016. It means that soon the volume of sludge will increase rapidly and the techniques for an effective sewage sludge utilization will be sought for.

The main component of sewage sludge is water (ca. 70-90%), and the remaining part is represented by organic matter (50%) and mineral fraction (50%) [3], which makes this waste material interesting for several industrial applications. High probability of releasing some toxic compounds like heavy metals into environment, practically excludes agriculture utilization of sewage sludge. However, a substantial organic load allows for converting this material into the form useful for energy generation.

To achieve this goal, in most cases the organic solids must be transformed into either gaseous or liquid phase, which is then used in special installation to energy production. Few processes allow for applying the organic matter directly in its raw, natural form (i.e. combustion). The techniques for final energy generation differ and depending on the expected results a concrete equipment should be applied. For both heat and electricity generation it will be a CHP unit (combined heat and power), for sole heat production it may be a simple engine, and for sole electricity some kind of turbine can be used. One of the newest devices applied for power generation based on the electro-chemical reactions is fuel cell (FC).

Fuel Cells

The general purpose of fuel cells is to convert the energy included in the ions into electrical power through chemical reaction. Fuel cell acts like battery, which does not need to be previously loaded. Fuel cells are built from two electrodes: cathode and anode, separated by the electrolyte membrane, which enables cations or anions flow between electrodes. The scheme of typical fuel cell is presented at Figure 1.

Six basic types of fuel cells are recognized [4-5]: phosphoric acid fuel cell (PAFC), polymer electrolyte membrane fuel cell (PEM), direct methanol fuel cell (DMFC), alkaline fuel cell (AFC), molten carbonate fuel cell (MCFC) and solid oxide fuel cell (SOFC). Simple characteristics of these systems are given in Table 1.

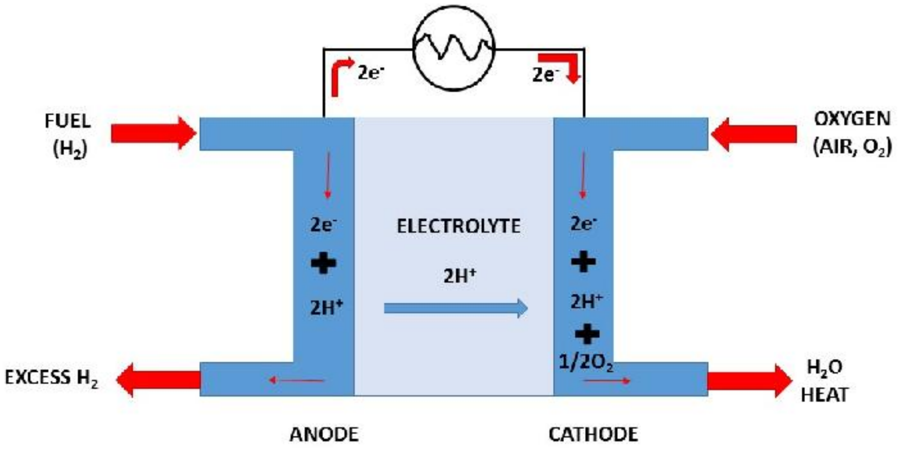

Fig. 2 Typical fuel cell.
Source: Author's

Table 1. Differences between basic types of fuel cells

FC type	Mobile ion	Operating temperature	Applications
PAFC	H^+	220°C	CHP units, about 200 kW
PEM	H^+	30-100°C	Mobile applications, vehicles, low power CHP units
DMFC	H^+	20-90°C	Low power portable electronic systems
AFC	OH^-	50-200°C	Space vehicles
MCFC	CO_3^{2-}	650°C	Large scale CHP units (up to 1MW)
SOFC	O^{2-}	500-1000°C	Wide range of CHP units (2kW-multi MW)

Source: [5]

Using fuel cells as an energy generator brings many benefits, including increased efficiencies and the lack of dangerous pollutants emissions [6]. Apart from hydrogen, which is employed in FCs most often and directly, there are other chemical compounds that can be used for fueling FCs and for hydrogen generation by reforming. These are: methane (CH_4), ammonia (NH_3), methanol (CH_3OH), ethanol (C_2H_5OH) or gasoline (C_8H_{18}) [5]. The examples of the reforming reactions are presented below ((1)-(3)) [5]. Depending on the type of fuel cell used for energy production, different requirements for fuel content are considered. For gaseous fuels they are summarized in Table 2.

$$CH_4 + H_2O \rightarrow CO + 3H_2 \tag{1}$$

$$C_nH_m + nH_2O \rightarrow nCO + \left(\frac{m}{2} + n\right)H_2 \tag{2}$$

$$CH_3OH + H_2O \rightarrow 3H_2 + CO_2 \tag{3}$$

Table 2. Fuel requirements in its application for different fuel cells

Gaseous compounds	PEM	AFC	PAFC	MCFC	SOFC
H_2	Fuel	Fuel	Fuel	Fuel	Fuel
CO	Poison (>10ppm)	Poison	Poison (>5%)	Fuel[a]	Fuel[a]
CO_2 and H_2O	Diluent	Poison[b]	Diluent	Diluent	Diluent
CH_4	Diluent	Diluent	Diluent	Diluent[c]	Diluent[c]
S (H_2S and COS)	unknown	unknown	Poison (>50ppm)	Poison (0.5ppm)	Poison (>1.0ppm)

[a] CO reacts with H_2O producing H_2 and CO_2, CH_4 with H_2O reforms to H_2 and CO faster than reacting as a fuel at the electrode.

[b] The fact that CO_2 is a poison for AFC rules out its use with reformed fuels

[c] Fuel in the internal reforming MCFC and SOFC.

Source: [5]

There are many processes and technologies that allow to provide conversion of solids into gaseous phase. It can be done by either thermal or biological processes. Among thermal processes both pyrolysis and gasification can be performed. Biological procedures that can be utilized for gas fuels production are anaerobic digestion or direct fermentation to biohydrogen.

Thermal processes

Gasification is the process in which solid fuel is converted into gas in the presence of oxygen or other oxidizing agent like air or steam [7]. At high temperatures of 800-1400°C, oxidation of carbon and cracking of tars and gases take place [8]. As a result of these processes, a high-quality flammable gas is produced. Its calorific values range from 4 MJ/m^3 (when air is used as gasifying agent) to even 10 MJ/m^3 (in the case of oxygen utilization); therefore, it can be used for heat and power generation [8]. The gas obtained after gasification of sewage sludge contains mainly carbon monoxide and hydrogen [7, 9]. Thus, it is considered for fueling the fuel cells for electricity production. Other gaseous compounds are: methane, ethane, ethene, nitrogen, and various contaminants. Nipattummakul and co-workers [10] in their work showed that steam gasification of sewage sludge might be very perspective and the hydrogen yield for the process conducted at 1000°C is 0.076 $gH_2\,g^{-1}$. Results of the other work [11] confirm this finding and indicate that the presence of water vapour and some catalysts like dolomite, alumina or olivine increases the content of hydrogen in obtained syngas. Some data are available that presents the optimal process condition for the efficient syngas production. These recommendations include: low (110-165°C) temperature in the dryer, proper grinding of the sludge prior gasification and utilization of indirectly heated dryer [8].

Latest research in the field of sewage sludge gasification concerns to increasing the hydrogen content in producer gas. It can be done by applying the two-stage gasifier [12]. Moreover, the tar and ammonia content after the process can be significantly reduced by using of the Ni-coated distributor. The tar removal was also a subject of other investigation [13]. It occurred that using a dolomite as a primary catalyst can increase the tar removal efficiency up to 71%. In the same study it was proven that the throughput influences the producer gas composition and the higher throughput is the lower hydrogen content in syngas.

One of the newest ideas for sewage sludge gasification is a method called supercritical water gasification (SCWG) technology, which involves the sludge hydrolysis in supercritical water followed by gasification of released oligomers [14]. Numerous studies have been performed both without and with the use of different catalysts [15-19]. Zhang and co-authors (2010) [15] investigated the influence of the type of sludge on hydrogen production during SCWG performed at 500°C and 37 MPa for 2 hrs. Their results show that the primary sludge gives more energy in the form of hydrogen (32%) than either secondary sludge (20% of H_2) or digested sludge (20% of H_2). Other research presents the comparison of the efficiency of SCWG of sewage sludge performed with or without K_2CO_3 as catalyst [16]. In this case the catalyzed gasification occurred to be less effective (47% of H_2) than the non-catalyzed process (47% of H_2). Some research were performed to improve the efficiency of the SCWG of sewage sludge by application different catalysts. Xu and Antal in their work used a coconut shell and activated carbon as a catalysts and obtained the syngas with the hydrogen content of 42% [17]. Other work [18] shows that sodium hydroxide is much better catalyst for SCWG of sludge and allows to product the gas with the hydrogen content higher than 76%. Another method studied recently for improving the gasification efficiency regarding H_2 yield is the conditioning the sludge with lime (CaO) prior to the thermal process [19]. The results obtained in discussed work indicate that the increase in the hydrogen production is caused by complete conversion of CaO into $Ca(OH)_2$ and its further distribution over the sludge matrix.

Second thermal process that allows for producing gaseous compounds used for feeding fuel cells is pyrolysis. In this process organic fraction of sewage sludge is thermally decomposed. The typical process conditions are: temperatures between 300 and 900°C, ambient pressure and oxygen-free atmosphere [7, 8, 20]. As a results of the pyrolysis different products are generated, depending on process conditions and method used. These are: solid char, water, water-soluble organics, tars and pyrolytic gas [20]. The final products may be grouped into three fractions [7]:

- solid (pyrolytic coke), charcoal including inert substances, dust, heavy metals;
- liquid, a mixture of oils, tars, water and organic compounds;
- gas (pyrolytic gas).

The efficiency of gas production is related to moisture content in sewage sludge. To achieve a high-calorific fuel drying procedure should be performed prior to pyrolysis [8]. Usually the gas includes: H_2, CH_4, CO, CO_2, N_2. Such pyrolytic gas can be utilized as a gas fuel itself [20].

Decomposition of sewage sludge during pyrolysis was a subject of many investigations. One of them [21] proved that the calorific value of gas produced as a result of such thermal process is about 23 MJ/m^3. Moreover, the composition of pyrolytic gas was determined as CO, CO_2, H_2 and C_1-C_4 hydrocarbons like CH_4, C_3H_3, C_2H_2, CH_2CO. The Authors showed that the share of gaseous form of final products increases with increasing the temperature of reaction. The changes of gas composition during pyrolysis were studied also by Conesa and co-workers [22]. They specified the three stages of pyrolysis by both temperatures and generated gaseous compounds. The first stage takes place at 250°C and leads to releasing such products as methane, carbon dioxide, acetic acid and water. Second one is performed at 350°C and brings also other compounds, which are prevalent. During the last stage (at 550°C) hydrogen, methane, carbon dioxide, alcohols and hydrocarbons are produced. This shows the importance of temperature of pyrolysis and its influence on further gas composition for its utilization in fuel cells. One of the recently published study concerns the flash pyrolysis of sewage sludge in a conical spouted bed reactor [23]. In this study the influence of the process condition on the product yields was investigated. It was proved that the liquid is the main product of the thermal process conducted at high temperatures, with the maximum at 500°C. Further increasing of the temperature led to the secondary reactions like cracking, which caused the decrease in the liquid yield and the increase in gas products yield. The highest concentration of H_2 in the gaseous phase was obtained at temperatures between 500 and 600°C as a result of both cracking reaction and dehydrogenation promoted by the catalytic effect of the inorganic fraction.

In other study Fan and co-workers [24] also investigated the influence of process temperature on the products yields during the pyrolysis of different municipal sewage sludges in a gas sweeping fixed-bad reactor. The results of their work confirmed that the main product of the sewage sludge pyrolysis is liquid (above 40% wt at 700°C), and the maximum gas production equals ca. 27.5 % wt takes place at temperature of 700°C. Hydrogen releasing started at 450°C and the rate increases vigorously from 600 to 700°C indicating sharp dehydrogenation and decarbonylation reactions.

To improve the yield of hydrogen in gaseous phase obtained as a result of sewage sludge pyrolysis new methods has been developed recently. One of them called biophysical drying (BDS) coupled with fast pyrolysis was described by Han and co-workers [25]. In this process good moisture removal rates are obtained and the energy consumption is decreased significantly compared to the traditional thermal drying. In consequence, the syngas and char yields of BDS pyrolysis were higher than those achieved for traditional process. Maximum syngas yield with H_2 content of 42.6% reached 33.4% for BDS pyrolysis performed at 900°C.

As it is described above both thermal processes: gasification and pyrolysis might be used for the conversion of sewage sludge into a valuable, gaseous product, which can be then used in fuel cells for electricity production. These processes are similar and have many benefits compared to incineration. Many ideas are presented that combine both the process for increasing the efficiency of sewage sludge degradation and its conversion into energy. One of them is Thermoselect Technology, which involves pyrolysis of solids and then gasifying of the obtained coke into syngas [26]. Another process – Noelle Conversion – is performed at high temperatures (>2000°C) and pressures (>3.5 MPa) [27]. Some works describe pyrolysis gasifiers as an equipment adequate for sewage sludge into energy conversion [20]. Very promising method being a combination of both pyrolysis and gasification (MWDPG – microwave-induced drying, pyrolysis and gasification) was described by Menéndez and co-workers [28]. Data related to an application of these thermal processes for electricity production in fuel cells is still very limited. An interesting work concerning two-step process has been shown recently by Sattar et al [29]. The investigators gasified different biochars formed via intermediate pyrolysis performed at 500°C obtaining high-quality syngas. The results suggest that the hydrogen production for all tested chars except woods was the highest at temperatures in range from 700 to 750°C and for the sewage sludge biochars it increased sharply once again after reaching 850°C. For sewage sludge biochars the highest H_2 yield (ca. 57 %) was observed at 850°C, however, this kind of chars occurred to be the least efficient for steam gasification compared to other tested materials. In the research presented by Jayaraman and Gökalp [30] it is stated that the pyrolysis, combustion and gasification of the dried sewage sludge may be considered as a primary pyrolysis and secondary reaction and the material is converted into tar, char and gas during the first step of the process performed at all tested ambiences (steam, argon, oxygen or their mixtures). The complete burn out of sewage sludge chars took place at 950°C and the gasification temperatures are lower than those obtained for *miscanthus* samples.

Biological processes

A second group of methods applied for feeding fuel cells by different gaseous compounds obtained from sewage sludge conversion is represented by biological processes. The most popular and perspective nowadays is application of anaerobic digestion (AD) as well as dark fermentation. First one is a multistage conversion of organic matter in which fermentative processes play the most important role. Second one in turn can be considered as a one of the stages of the previously mentioned AD. As a result of these processes different products are obtained. While dark fermentation leads mainly to hydrogen generation, its extension with further steps gives in consequence biogas – the gaseous mixture of two main compounds, namely methane and carbon dioxide.

Anaerobic digestion has been used successfully for sewage sludge degradation for many years. It is a conversion of organic matter into gaseous phase by metabolism of some specialized species of anaerobic microorganisms. The presence of oxygen is thus unwelcome. This process is carried out both at mesophilic (ca. 35-40°C) or thermophilic (ca. 55°C) conditions [30]. During several complex biochemical reactions organic structures like carbohydrates, lipids and proteins are transformed first to simpler compounds (sugars, fatty acids and amino-acids, respectively), subsequently to acetic acid and hydrogen, and finally to methane and carbon dioxide [32]. This biological process may be performed as a mono-substrate digestion (when only sewage sludge is used as a feedstock) or as a co-digestion (when the mixture of sewage sludge with other organic matter(s) is utilized) [33]. Both ways are beneficial and effective from the economical point of view, but co-digestion may bring additional advantages, like higher methane content in produced biogas or higher efficiency in biogas production.

In 2010 Dubrovskis with co-workers [34] compared biogas yield and methane production from different types of sludge. They determined that both biogas and methane production depend on the kind of sludge and the highest energetic efficiency can be expected when fresh sludge is utilized (biogas – 397 dm^3 kg$_{VSd}^{-1}$; methane – 233 dm^3 kg$_{VSd}^{-1}$). The worst results were obtained for longterm stored sludge (biogas – 264 dm^3 kg$_{VSd}^{-1}$; methane – 122 dm^3 kg$_{VSd}^{-1}$). In other research [31] the influence of temperature condition on methane production was studied. It was shown that mesophilic single-stage AD of sewage sludge is more effective than thermophilic process, though the differences are insignificant (451.1 and 416.0 cm^3 CH_4 g$_{VSrem}^{-1}$, respectively). These Authors confirmed also that co-phase process (meso- and thermophilic) may bring similar results to those for single-stage mesophilic process, with methane yield between 424 and 468 cm^3 CH_4 g$_{VSrem}^{-1}$. Recently published work of Liao et al. [35] indicates that the role of thermal pre-treatment in biogas production from sewage sludge is significant. Such technique can improve the solid-state anaerobic digestion efficiency both increasing biogas yield by 11% and decreasing the fermentation time from 22 to 15 days.

Possibility of an effective co-digestion of sewage sludge with other organic wastes was investigated by Sosnowski and co-workers [33]. In their studies organic fraction of municipal solid waste (OFMSW) was used as a co-substrate. The obtained results indicated that co-digestion was more efficient than single digestion of sewage sludge (460 and 240 dm^3, respectively), and that the cumulative biogas production in the case of co-digestion increased with increasing the proportion of OFMSW. Recently Nghiem and co-workers [36] have analyzed co-digestion of sewage sludge with glycerol. In the pilot-scale experiments they proved that crude glycerol can be used as a co-substrate for on-demand biogas production from sewage sludge, and that the additional volume of methane produced was 1.3 m^3 dm^{-3} of glycerol. This is in agreement with the other studies on such co-digestion [37] that showed an efficiency increase in biogas production with the increase of the volume of glycerol added, until its critical concentration of 1% (v/v) in the feedstock. On the other hand there are some works showing that crude glycerin may influence the biogas production negatively when mixed with sewage sludge [38]. Negative effect of co-digestion of sewage sludge with different microalgae species was described recently by Caporgno et al. [39]. Both biogas and methane production observed in co-digestion were significantly lower than for sole sewage sludge digestion. These results were the same for the mesophilic and thermophilic conditions.

There are at least a few papers describing either today existing power plants combining anaerobic digestion with fuel cells or their lab-scale simulations. De Arespacochaga et al. [40] in their work described the pilot-scale plant for sewage biogas production and fueling SOFC. The system was operated at O/C ratio of 2, stack temperature of 800°C and reforming temperature of 550°C. The obtained efficiency for co-generation was about 60%, and the heat-to-power ratio was 0.8. The preliminary result suggest that afterburning of some volume of biogas is necessary to achieve thermal self-sufficiency. The example of the simulation of the system with MCFC is the paper presented by Verda and Sciacovelli [41]. These authors used the experimental data from the digester to build the model of such system and to investigate some variations. The obtained results indicate that the costs of such unit are comparable with market prices of electricity and the expected efficiency should not be lower than 50%. One of the latest work concerning the system of fuel cells feeding with biogas is simulation study written by de Arespacochaga et al. [42]. These Authors compared the economic and technical aspects of different FC systems with traditional cogeneration combining micro-turbine and internal combustion engine. MCFC occurred to be the most efficient with the capability of improving the electrical self-sufficiency of the industrial-scale power plant by 60%. Although the systems consisting of SOFC were characterized by technical performance similar to those systems with combustion engines, their industrial deployment is still unprofitable economically. The general conclusion of this work is that both biogas producers and fuel cells manufacturers should work together on the field of such combining systems to overcome the limitations and improving existing small-scale power plants.

Hydrogen production via fermentation (dark-fermentative H$_2$ production) is the other way to convert sewage sludge into feedstock for fuel cells. This method is environmentally friendly and economically reasonable, so it is attracting more and more attention. The process is carried out by fermentative microorganisms like facultative (*Klebsiella pneumoniae, Enterobacter* and *Bacillus sp.*) and strictly anaerobic bacteria (*Clostridium butyricum*) [43]. The overall aim is to keep the electron balance between donors and acceptors. A key role in this process is played by the group of enzymes (hydrogenases), which either oxidize H$_2$ to protons or reduce protons to release molecular hydrogen [44]. H$_2$ production during dark fermentation can be described with two equations, (4) and (5), given below:

$$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 2CO_2 + 4H_2 \tag{4}$$

$$C_6H_{12}O_6 \rightarrow C_3H_7COOH + 2CO_2 + 2H_2 \tag{5}$$

The theoretical maximum hydrogen yield in the above reactions is 4 moles of H$_2$ per one mole of glucose [44]. Moreover, simultaneously either acetate or butyrate is formed. Similarly to anaerobic digestion, the process can be performed in mesophilic or thermophilic conditions. Other important parameters are pH of the fermentation broth and C/N ratio. Due to the fact that different VFAs are generated, the pH should be continuously monitored to avoid rapid decrease and further inhibition of microorganisms' growth.

Although its expected potential is high, the available data on biohydrogen production from sewage sludge is very limited. Some of the sources claim that dark fermentation of sewage sludge in insufficient (0.16 mg H$_2$ g^{-1} of dried solids (DS)); on the other hand others recommend a pre-treatment step for increasing the efficiency of biohydrogen production [45-46]. Cai and co-workers in 2004 [47] stressed the importance of alkaline pre-treatment and initial pH for further H$_2$ production. High initial pH value for raw sewage sludge (pH>10) was beneficial for renewable energy production. The highest H$_2$ yield was obtained for alkaline pre-treated sewage sludge at initial pH of 11.0 (16.9 cm^3 g^{-1} DS). Moreover, it occurred that the higher initial pH led to slower consumption of this gaseous bioproduct, which makes the process more stable. Similar investigation of the influence of sewage sludge pre-treatment on further H$_2$ production was performed by Xiao and Liu [48], who applied sterilization as a pre-treatment step. The results indicated that such operation accelerate biohydrogen production and reduce methanogens activity. The observed increase in H_2 generation was very high (16.3 cm^3 g^{-1} volatile solids (VS) in comparison with 0.35 cm^3 g^{-1} VS obtained for untreated sewage sludge). Additionally, due to NH_4^+ production, only small decrease of pH took place; volatile acids were neutralized with the ammonia. Apart from the pre-treatment step prior to sewage sludge dark fermentation, also co-fermentation of sewage sludge with different organic wastes for biohydrogen production is also considered. Zhu and co-workers [49] found this process very beneficial for H_2 production, when the mixture of primary sludge, activated sludge and food wastes is used. All combinations of these wastes led to an increase in hydrogen production potential, and the maximum yield of 112 cm^3 g^{-1} VS was obtained for co-digestion of all three wasted components. According to the Authors, such improvement was a consequence of the increase in the buffer capacity. Similar investigation was conducted by Kim et al. [50], who showed that co-fermentation of food waste with sewage sludge brings better results than H_2 production from food waste only. Tyagi and co-workers [51] also studied the potential of co-fermentation of sewage sludge with OFMSW (organic fraction of municipal solid waste). The process performed at thermophilic conditions occurred to be much more efficient in hydrogen production than sole anaerobic digestion of sludge. The maximum yield of 51 cm^3H_2 g^{-1} VS consumed was obtained at OFMSW to mixed sludge ratio of 5:1 and at TS concentration of 20%. Another work in the field of co-digestion of sewage sludge for hydrogen production was presented by Kim et al. [52]. These Authors used the mixture of the sludge and rice straw in two different systems: one-stage for methane production and two-stage for combined generation of hydrogen and methane. The results showed the great potential of the two-stage system for bioenergy production (H_2 production of 21 cm^3H_2 g^{-1} VS at the first stage and CH_4 production of 266 cm^3CH_4 g^{-1} VS at the second stage of the process). The total bioenergy yield obtained for the combined system was almost 60% higher than the yield for one-stage system.

Summary and conclusions

The presented short review of potential applications of sewage sludge for feeding fuel cells confirms the significance of research in this field and its potential impact on closing the material and energy loop, promoted among others by the European Commission's strategy "Innovating for Sustainable Growth: a Bioeconomy for Europe". Several knowledge gaps have been identified, including new catalysts for the efficient syngas generation or new bacterial strains for hydrogen fermentation. Taking into account the fact that the global volumes of sewage sludge will be increasing, good practices in sewage sludge management will become more and more important as well. Due to the low efficiency of some of the techniques analyzed, further engineering work is also necessary, with new methods for sewage sludge utilization designed and tested in the field. Application of safe, economics and ecological products based on sewage sludge in microbial fuel cells is a viable technological solution, which offers also promising industrial prospects by providing solutions to the acute problems resulting from the increasing quantities of sewage sludge production. Reinventing the current approach to this waste through its processing and feeding into the fuel cells seems to be an economic and safe method of waste disposal and can be performed in different ways or systems.

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THE INNOVATION CHAIN IN RAIL TRANSPORT

Abstract

The paper proposes a classification of innovations in rail transport by compiling a catalog of innovations and introduces the notions of innovation diffusion and innovation chain. It also provides examples of innovative products and technology solutions developed by Polish manufacturers.

Key words

innovation, railways, innovation chain, innovation diffusion, rail industry, Poland.

Introduction

For more than a decade, the transport sector has been experiencing a proliferation of innovations. We have seen major developments in transport vehicles and transport infrastructure as well as in freight and passenger services. We can observe also innovations in funding methods and business models. Some of the innovations were previously unknown or impossible to implement, but now, supported by information systems, the Internet and mobile communications, they have become industry standards.

The paper seeks to propose a classification of innovations in rail transport. The discussion is illustrated with examples of innovative products that made a difference in Poland's rail transport sector: new or significantly enhanced products and services that led to major improvements in the quality and competitiveness of rail transport services.

Definitions and types of innovation

In the most general sense, the word "innovation" stands for introducing something new (in Latin: innovatio means "renewal", while novus means "new"). Diverse definitions of innovations can be found in numerous publications prepared by both Polish [1] [2] and foreign scholars [3] [4] [5]. Under the definition advocated by the OECD and the European Commission, innovation must be implementation-oriented: it is indeed "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" [6, p. 46]. An innovation should therefore be perceived either as something that is newly implemented or as implementing something that is new to:

- the implementing organisation although it is already used by its competitors (e.g. selling tickets online),
- a given sector/industry, albeit employed in other sectors/industries (e.g. hybrid vehicles or usage-based billing for traction power),
- a geographic area, e.g. in a given country (although they are known and utilized in other countries, e.g. ERTMS (European Rail Traffic Management System)/ETCS (European Train Control System)).

Literature on the subject uses a variety of criteria to distinguish different types of innovation [1, pp. 92-95] [4] [7, pp. 11-27]. Common types relate to new materials, new products, new services, new processes, new organizational forms, as well as nee business models. The third edition of Oslo Manual [6] adopts a distinction into four basic categories of innovations: product innovations, process innovations, marketing innovations, and organizational innovations. Product innovations and process innovations are closely related to the concept of technological product and process innovation (TPP) used in the second edition of the Oslo Manual.

As Damanpour and Schneider [3, p. 216] emphasize “innovation is studied in many disciplines and has been defined from different perspectives”. In the transport and logistics sector, a product innovation corresponds to the introduction of a good or service that is new or significantly improved in terms of its characteristics or intended uses, or whose performance is significantly better, to the effect that it provides the customer (user, passenger, forwarder/shipper, carrier, etc.) with clearly new benefits or added value. Therefore, this type of innovations is often called service product innovation. The terms “service product innovations” and “product innovations” have been used interchangeably in the literature to describe a particular set of innovations in service companies [8, p. 566]. The theory of innovation in services developed by Gallouj and Weinstein [9] has been widely discussed in service innovation literature [10, p. 139] [11]. Many researches also highlight that innovation does not just take place in products, but also in processes, and potentially, innovation can be combined from both process and product [11, p. 1361]. Several studies used a typology of service innovation that includes three modes: business model innovation, service product innovation, and service process innovation [4, p. 1362].

A process innovation denotes the deployment of a new or significantly improved production or delivery method (process) in various aspects of transport services, vehicle manufacturing, or transport management processes. It can involve significant changes in one or more of the elements of a process, such as: organization, technology, human resources, work methods, equipment, etc. Accordingly, an organizational innovation stands for the implementation of a new organizational method in a transport company’s business practices, workplace organization or external relations.

Innovation is always linked to the notion of benefit or added value that a specific innovation brings, on the one hand, to suppliers – by enhancing their products or services portfolio and hence increasing their sales, operating margins or brand awareness – and on the other, to customers – by reducing the demand on their time or labor or by increasing the reliability of a product or service they use. In other words, innovations should benefit both the parties to transport-related (or, broadly speaking, logistics-related) transactions. A question arises, therefore, whether an innovation that makes no difference to either party makes any sense. Assuming that, conceivably, somebody did see good reasons to develop and implement the innovation, the question should perhaps be restated as follows: were all the uses of the innovation correctly identified and fully “exercised”? Was everything done to convince the organization and the customers that the innovation contributes added value, even if it is difficult to capture because it affects such things as public relations, user opinions, or following a trend or fashion?

Innovation chain in the transport sector

A distinctive characteristic of 21st century innovations in the transport sector is that they will concern all elements and stages of the transport process. In some cases, it is difficult to discriminate between product-, service- and process- related innovations, as they will overlap and intermingle: a product innovation project centered on a vehicle might at the same time entail a process innovation at the design or manufacturing stage. This is also true about some services. Baregheh *et. al.* defined innovation as “the multi-stage process whereby organizations transform ideas into new/improved products, service or processes, in order to advance, compete and differentiate themselves successfully in their marketplace” [4].

It could be therefore theorized that no innovation should be viewed outside its context and without taking account of its place in the value chain and the supply chain. A change (innovation) introduced at one point implies or enables changes to other links (elements) in the chain: streamlining a process, launching a new service, creating a new customer service process, or developing an entirely new business model, to name just a few such changes. Recognizing how important it is for innovation to propagate throughout supply chains, Laskowska-Rutkowska has put forth the concept of “diffusion of innovations in a supply chain” [1].

Innovations to design and manufacture processes yield new or modified products, characterized by new features, properties or capabilities in terms of, for example, durability, consumption of materials, pollutant emissions, reliability or safety. Product innovations like these (involving components or final products, such as vehicles or transport infrastructure systems) will soon inevitably result in the provision of new or modified services (internal as well as external), and hence will lead to transforming or developing the underlying service delivery processes in which the new or modified products have been deployed. The emergent service innovation might, in turn, trigger changes in the subsequent service use process. A chain of innovation can be longer or shorter, it may be, for example, truncated to a service alone or to a service and some related processes, but in most cases seemingly isolated innovations can be in fact traced back to a prior global and universal innovation, such as e.g. mobile telecommunications or the Internet.

Given these facts, it is possible to define a chain of innovation in transport as an alternating sequence of product, service and process developments such that applying an innovation to a single element allows modifications to other elements aiming to derive (economic, social, environmental, etc.) benefits from their use.

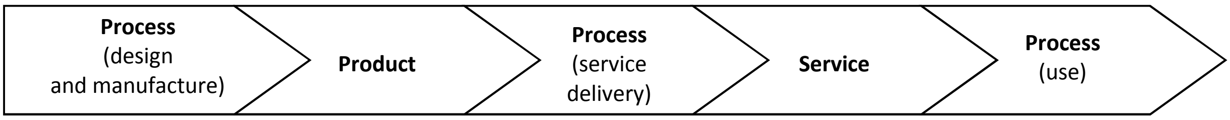

Fig. 1. A chain of innovation in the transport sector
Source: Authors'.

An innovation chain is exemplified e.g. by the process of rapid design, visualization and simulation of vehicle chassis and interior, enabling engineers to build multiple variants of a vehicle and demonstrate them to the customer at an early stage of development. Some of these variants may be approved for production or offered as an after-sales option (i.e. after the vehicle, a passenger car in this case, comes into use). As an effect, buyers – vehicle fleet owners (e.g. a so called RoSCo – Rolling Stock Company) – can enhance their service delivery processes by offering operators (e.g. passenger transport operators) the rental of, besides basic non-modifiable vehicles, customizable vehicles whose interiors can be reconfigured by users to suit their specific needs, either one-time prior to use or multiple times (e.g. on weekdays or on weekends – a weekday vs. a weekend setup), depending on the flexibility of a particular design.

To demonstrate the complexity of the innovation chain in rail transport this paper attempts to arrange innovations into three groups – product (technology) innovations, service innovations, and process innovations – and to categorize them at different levels.

Product innovations in rail transport

Product innovations can involve rail vehicles, transport infrastructure, or both. They will include, primarily:

1. Interoperable multi-system rail vehicles that can operate with diverse types of traction power networks and systems.
2. Signalling systems of ERTMS/ETCS or PTC (Positive Train Control) class providing for interoperability on main lines or allowing continued use of low-traffic lines as a result of substantial cost savings on infrastructure maintenance.
3. The development of base models of products (e.g. vehicles) with multiple variants that are customizable to user preferences (specifications), and the construction of user-configurable vehicles (mostly for passenger transport) that can be easily adapted to users' temporary requirements, e.g. to meet demand for extra business class seats or to cater to special-needs groups (persons with small children, tourists, cyclists, people with reduced mobility).
4. Various types of flat platform wagons for intermodal (containerized) transport.
5. The application of composite materials and nanomaterials to reduce vehicle weight, thus bringing down energy consumption, and to optimize surface finishes (dirt-resistant outer shell coating/sheathing, window glass as well as seat upholstery and other elements of interior decoration characterized by very high dirt or liquid resistance).
6. Electric cars with solutions addressing the last mile problem, enabling them to cover short distances using stored energy or auxiliary diesel engines (as when moving in industrial spurs and other secondary tracks, entering a repair facility, or providing mobility in case of traction power loss) and hence reducing the need for replacement or shunting vehicles.
7. Diesel engines with lower and lower greenhouse gas emissions.
8. Electric engines of increased efficiency.
9. Hybrid cars powered by diesel and electric engines.
10. Hydrogen cell technologies.
11. Inductive (wireless non-contact) electric vehicle charging systems for large road and rail vehicles (trams, buses, trucks, etc.).
12. Kinetic and thermal energy recuperation mechanisms and systems.
13. Mechanical energy storage devices (modern "flywheels").
14. Section switching of traction current – pedestrian-safe third rail systems for trams and trolleybuses.
15. Photovoltaic power and wind power for selected infrastructure components.
16. Noise reduction systems – internal and external, active or passive.

17. Closed circuit systems for water, liquid waste and operating fluids to prevent leakage.
18. Crash zones and safety cells in rail vehicles.
19. Radio systems for remote control of locomotives operating in closed areas or using of switch engines in industrial yards.
20. Radio and telecommunication systems, including voice and data transmission systems, such as GSM-R.
21. Internet access (WiFi) inside vehicles and passenger service facilities (e.g. on stations).
22. Traction control and anti-slip systems.
23. Anti-collision warning systems, with an autonomous emergency braking feature, installed in road and rail vehicles.
24. Integration or unification of communication and data exchange standards among onboard control systems.
25. Diagnostics systems including:
    - automatic reading and interpretation of diagnostic information and alerts,
    - data recorders and black boxes,
    - rolling stock condition monitoring devices (eg. DSAT),
    - infrastructure surveillance systems to prevent unauthorized access,
    - predictive diagnostics.
26. Wild animal deterring devices installable along railroads.
27. Hybrid solutions addressing pedestrian crossing safety on roads and railways (illuminated traffic sign frames, crossings with lights-on switching on detecting an oncoming vehicle, or warning systems dedicated to non-guarded road-rail crossings).
28. Transport planning and management support systems based on state-of-the-art information technology, involving the use of algorithms and databases to help optimize the planning and monitoring of shipments as well as the deployment of personnel and rolling stock, or scheduling routes and timetables.
29. CCTV surveillance, panic/anti-theft alarms, intercom systems for communication between passengers and cabin crew (including the driver).
30. Passenger information display and voice announcement systems (for use both in vehicles and facilities) as well as infotainment solutions combining information with entertainment or advertising functions (interspersed with information content).
31. Improvements in travel ergonomics and comfort, including new appliances and solutions to facilitate the delivery of transport services to elderly and disabled persons (e.g. with mobility handicaps or sight and hearing impairments), such as stair lifts and platform lifts, drive-up ramps, pull-out steps and ramps, door buttons (including Braille buttons) activating car doors, pagers (beepers), voice and video announcements, voice/sign language translation kiosks, seats for wheelchair users (equipped with belts or other fasteners), wheelchair accessible toilets and passages, seats for mothers with infants.
32. Training simulators, including 3D visualisation systems.
33. New transport vehicles, e.g. aircraft- or helicopter-type drones used for rail cargo tracking as well as railway infrastructure monitoring.

Service innovations in rail transport

While it is true that most service innovations are associated with innovative products whose availability has driven efforts to introduce new services, wherever it is the service that plays a more significant role, such innovations are deemed to belong in this category:

1. Short- or long-term rental of transport vehicles where the service includes hire of personnel and maintenance.
2. Internet-based customer experience, automation of sales and information desk functions, mobile solutions (tickets, timetables, info- and helpline, parcel tracking).
3. Cargo tracking and micro cargo delivery (courier services, containerized cargo as well as bulk cargo).
4. Mapping of traffic flows and passenger behaviour (transport planning) through e.g. the use of vehicle count systems (roads), passenger count systems (public transport), and trip (origin-destination) matrices.

This category can also comprise two product-process-service aggregates in which the service factor is prevalent. These include:

5. Intermodal transport, which is not in itself an absolute novelty, as it dates back to around the middle of the 20th century. Increasingly supported by modern information technologies and hence easier to handle (single large shipments have become convenient to describe, identify, move, track and transfer

between modes of transport), intermodal transport has been growing ever since. Nowadays one may indicate also growth of unified passenger intermodal transport (rail-bus-tram-(air) at least).

6. Low-cost railways, a concept/model that was originated and first implemented in air transport in the US (South-West Airways), has been growing dynamically in Europe since the late 1990s, chiefly as a result of deregulation in most European markets, previously monopolized by government-run companies. The “low-cost carrier” service (internally: process) is based on a blend of two ideas. First, it is a minimum services portfolio built around a single service that must be kept as cheap as possible while some add-on and à la carte features, such as meals, extra luggage, or call centre services, are offered at a much higher margin. Second, it is a unique ticket pricing policy: when booked early, tickets are sold at very low, almost negligible prices. It appears that this combination ensures an immediate market success.

Process innovations in rail transport

Process innovations can relate to design and manufacture, service delivery, or use of services. The first group includes, for example:

1. Building vehicles or e.g. control and communication systems from standard manufactured elements, preferably from easily available COTS (commercial off-the-shelf) components, that could be used across all product families.
2. Rapid design supported with 3D modelling and prototyping as well as with endurance testing and MES analysis.

The second group, encompassing processes that support service delivery, includes e.g. the following:

3. Construction and maintenance processes, including:
   - public contracts of the “design-and-build” or “design-build-and-maintain” type,
   - outsourcing of fleet and infrastructure management (may be limited to certain subsystems) – annual and multiannual contracts.
4. Funding models (schemes):
   - for transport infrastructure, e.g. public-private partnership (PPP), project finance models, licensing and permits, etc.,
   - for vehicles and fleets of vehicles, such as leasing, rental, and group purchasing organizations (GPOs, sometimes in *ad hoc* form) allowing buyers to achieve economies of scale and leverage their purchasing power.

The last group of innovations, viz. those pertaining to use processes, comprises e.g. the following:

5. Use of techniques based on energy-efficient dynamics for the acceleration and braking of trains.
6. Maintenance processes based on accurate and up-to-date information on a vehicle’s or device’s condition rather than on average inspection intervals.

Examples of innovations in the Polish rail market

Railway industry has a long-standing tradition in the area of today’s Poland (this includes territories that were formerly controlled by other states). At the moment, the railway industry is made up of over 200 significant actors, among which there are both global and local players. Transport services are provided by more than 80 licensed railway undertakings. Illustrative examples of innovations that have already been deployed in Poland’s rail transport market are provided in Tables 1-3.

Table 1. Examples of product innovations in Poland’s rail sector

Innovation	**Domestic examples**
Multi-system vehicles	Newag, Pesa
Multi-variant and customizable vehicles	Pesa, Newag, Solaris
Track superstructure components	Track Tec, KZN Bieżanów
Application of crash technology to the construction of car bumpers	Axtone
Wild animal deterrent devices	Neel
State-of-the-art materials, crash zones, safety cells, closed circulation of water, liquid waste and operating fluids	Alstom PL, Solaris, Newag, Pesa, Modertrans, FPS Cegielski
Modern engines and energy sources, last	Bombardier & Solaris, VISSystem, Pesa (*Marathon*), Newag

mile solutions, power-packs	
Interoperational ERTMS/ETCS systems	Bombardier PL, Thales PL
Remote control of switch engines	ArcelorMittal PL (user)
Communication	APM, Radionika, Pyrylandia, Kapsch PL
Internet access (WiFi) in transport vehicles	T-Mobile in partnership with PKP Intercity, Koleje Mazowieckie, some of the rail vehicles operated by Koleje Śląskie and Koleje Dolnośląskie
Diagnostics	Bombardier PL, VAE TENS, EC, ATM
Road and rail safety	KZA Kraków (Dysonapp system), Bombardier PL, Kombud, KZA Lublin, Sygnały Rybnik, APM
Transport planning and optimization systems	PKP PLK SA, PKP Informatyka, Basement Systems, Nodus, DPK, and many more in the IT industry
Simulators	I3D
Passenger information display and voice announcement systems; infotainment	KZŁ, R&G, TK Telekom

Source: Author's.

Table 2. Examples of service innovations in Poland's rail sector

Innovation	**Domestic examples**
Internet-based customer services, sales process and help desk automation, mobile solutions, passenger train tracking, mobile ticket booking platforms	PKP PLK, PKP Informatyka, TK Telekom and its subcontractors, Astarium Koleo, blik, moBilet, SkyCash, jakDojade.pl, e-podróżnik.pl, and many more
Tracking of locomotives, wagons, cargo shipments	Wasko, Elte, and many other
Combined services including manufacture, delivery and assembly of railroad switches	Track Tec, KZN Bieżanów
Low-cost rail connections	PKP Intercity (*TLK* trains)
Premium service	PKP Intercity (*Pendolino* trains)

Source: Author's.

Table 3. Examples of process innovations in Poland's rail sector

Area	**Distinctive characteristics**	**Domestic example**
Design	Unification/standardization, reliance on COTS components, FEM modeling and analysis, 3D design	Newag, Pesa, Solaris, EC Engineering, Inteco and other
Infrastructure and fleet financing schemes	Financing models for transport infrastructure (public-private partnerships, project finance models)	Pomorska Kolej Metropolitalna
	Funding models for cars and fleets (leasing, group purchasing organizations allowing buyers to achieve economies of scale, rental)	Południowa Grupa Zakupowa (covering 4 regions)
Construction and maintenance processes	Development and maintenance process: - types of public contracts, e.g. *design-build* or *design-build-maintain* - maintenance process outsourcing in regard of infrastructure or its subsystems (annual and multiannual contracts)	PKP PLK

Source: Author's.

Examples of product innovations by Polish companies

PESA BYDGOSZCZ

The reputation of Polish innovative technology has been built, to a large extent, by PESA – the Bydgoszcz-based rolling stock manufacturer and the first company from Central-Eastern Europe to have won, in March 2014, the prestigious Boldness in Business award by *The Financial Times* and ArcelorMittal. In 2015, PESA emerged as one of the world's leading tram manufacturers.

The milestones in the company's innovation success story include:

- 1994 – the first foreign contract to make sleeping cars for Lithuania.
- 1995 – ZNTK Bydgoszcz (company's former name) obtains a patent for a non-sparking brake shoes for rolling stock.
- 2001 – the company starts making the railbus called *Partner*. A further series of vehicles based on the *Partner* soon to follow.
- 2004 – the first wide-gauge diesel engine powered railbus made for Ukrainian railways. Launch of the EN95 class electric multiple unit (EMU) for the Warsaw Commuter Rail (Warszawska Kolej Dojazdowa – WKD), the Polish capital's suburban transit system.
- 2005 – entry into the tram market. Its latest tram model named *Twist* can recuperate energy while decelerating and return it to the network (or, optionally, store it in energy containers). Under emergency conditions, it is possible to use the stored energy to move the tram. Since the trams support online diagnostics, fleet managers can remotely monitor them.
- since 2006 – the company supplies diesel- and electric powered rail vehicles (including the *ELF* family) to all regions of Poland as well as to Ukraine, Lithuania, and Italy.
- 2012 – an electric locomotive developed as part of the *Gama* modular locomotive family, which includes locomotives powered by a 2400 kW diesel engine and capable of a maximum speed of 160 km/h alongside an electric locomotive line comprising single-system (with the optional *Marathon* auxiliary diesel engine allowing it to cover a minimum distance of 42 kilometres) and multi-system locomotives powered at 1.5kV DC, 3kV DC, 15kV AC or 25kV AC and doing up to 140 km/h in freight transport or 200 km/h in passenger transport. A key characteristic of the Gama locomotive family is the use of standardized modules that can be mounted on different types of locomotives, making the cars a lot easier to service.
- 2015 – first *Dart* trains delivered – a new generation of intercity class EMU trains geared to meet the requirements of European and global operators for long-distance lines. *Dart* units can be powered by a range of voltages and run at operating speeds of up to 250 km/h.

NEWAG

In its early years in business, the company specialized in maintenance and upgrading locomotives for passenger and freight rail operators present in Poland's market. Here is a brief record of the company's innovation achievements:

- 2005 – the premiere of a new EMU of the 14WE series; upgrades to diesel powered locomotives: 6D, 16D, 311D.
- 2009 – the new build 19WE EMU launched as well as the *Dragon* electric locomotive, the only wholly Polish-built car in 25-years' time, designed to haul heavy cargo trains.
- 2010 – the introduction of the first diesel multiple units (DMU) SA137 and SA138.
- 2011 – a contract signed between the Siemens-Newag consortium and Metro Warszawskie [Warsaw Metro] for the delivery of 35 six-car *Inspiro* trains.
- 2012:
    - the new *Nevelo* 126N tram developed;
    - the electric six-unit train 35WE – first in the *Impuls* family. *Impuls* multiple units can be shipped in a number of configurations (from two to six cars per unit). Besides variable length, multiple variants of passenger car interior are available, which makes the trains suitable for urban and suburban use as well as for long-distance routes. In 2013, a multiple unit from the *Impuls* family exceeded 211 km/h, setting Poland's speed record;
    - launch of the E4MSU *Griffin* from a family of 4-axle electric engines, the first Polish multi-system locomotive.

At the international ERCI Innovation Awards event held in November 2015, Newag was named Europe's most innovative rail company, over such competitors as Alstom and Ansaldo Breda. The award-winning project

"Europe's first Polish-built TSI-compliant 6-axle multi-system electric locomotive for heavy freight trains" was co-funded by the National Centre for Research and Development (NCBR). An international jury assessed runner-up projects on three aspects: innovative merit, effect on strengthening the company's competitive advantage, and networking with other enterprises and research institutions.

TRACK TEC

Track Tec Group is a leading supplier of track superstructure materials and elements. The Group is composed of seven manufacturing plants or facilities, three of them making railroad turnouts and fastenings, and the other four producing railroad ties and sleepers. The Group's principal product lines are pre-stressed concrete and wooden track sleepers, railroad and tram turnouts, rails, as well as level crossing plates, platform elements, and water and cable ducts. Track Tec designates itself as a one-stop shop for track construction, providing a comprehensive range of products and services including: engineering and design, manufacturing, transport and logistics, assembly and installation, alongside technical assistance, servicing, and maintenance inspections.
Its most recent innovation is a crossover switch supported on pre-stressed concrete sleepers and characterized by the application of entirely new solutions to the design of its components. The crossovers will be mounted on dedicated pre-stressed concrete sleepers instead of on traditionally used wooden ones. This will not only extend their life but also enhance their performance characteristics, e.g. increasing the travel speed to 120 km/h. In 2015, the product was awarded the "Rail Market's Engine" prize in the "Innovation" category.

Another highlight among the company's services is the highly innovative Track Tec turnout construction train, capable of transporting turnout parts on pre-stressed concrete sleepers. Before that, segments of that size were not carried by rail in Poland, as it involved the use of specialized vehicles that were not available domestically. The method developed by Track Tec uses three wagons to ship a fully assembled, ready-to-install turnout to any given location within the railway network. Its novelty lies in the use of the technical device UR-1, which was built in collaboration with EC Engineering and, when installed on a wagon, makes it possible to safely transport factory-assembled turnout parts on pre-stressed concrete sleepers to the construction site and to install them directly from the wagon onto the track bed.

The next step was to complement their service offering by providing a complete logistics service. To go with their wagons, the company purchased several electric and diesel powered locomotives, a railroad crane with a lifting capacity of 45-tons, capable of load-lifting under overhead lines, as well as some self-unloading wagons. The method described above reduces the time to complete trackwork, thus minimizing track closures resulting in inconveniences for operators and their customers. Owing to a progressive logistics solution, the order processing time has shrunk from six weeks to just a couple of days. The turnout construction train (*PZR*) won the first award in the "Rolling Stock" category in the Ernest Malinowski Contest held as part of the 2015 TRAKO fair in Gdańsk, Poland. The first customer order was filled by the *PZR* train in December 2015, by transporting two R300 turnouts from manufacturing site to assembly location distant ca. 100 km. It took around two and a half hours to lay a single block. The state-owned infrastructure manager PKP PLK intends to start using the method widely in assembling, transporting and installing turnouts on Polish railways.

NEEL

This Warsaw-based company was established in 1993 by former employees of the Railway Science and Technology Center (renamed the Railway Institute in 2010). The name is said to have been derived from the phrase "New Electronics for New Ecology". NEEL delivers systems protecting people's as well as animals' safety that reflect a commitment to promoting peaceful coexistence of humans and nature. Following a decade of research and development effort, the company built and launched a device representing a globally unique innovation – the UOZ-1 animal protection (deterring) device for installation along railway tracks. For several years now, the device has been operational in Poland and Russia, and is reported to deliver top performance.

The design of the revolutionary UOZ-1 animal protection device draws on a thorough understanding of rail traffic, animal behaviour and on the use of authentic animal sounds. It is activated by an approaching train and disabled as soon as the train moves away far enough. Its operation is founded on what we know about animals and their behaviour, and appeals to their survival instinct. Therefore, natural acoustic signals are utilized to deter them – a universal code understood by nearly all species of large animals. The UOZ-1 devices can be installed at intersections of railways and animal migration routes, minimizing losses in animal populations attributable to collisions with high-speed trains. Admittedly, accidents involving big animals, such as elk, deer, or a pack of wild boar, may be also hazardous for trains and passengers.

As a matter of fact, animal collisions have become an issue for many rail operators. In 2014 PKP Intercity, a major Polish passenger rail operator, spent nearly 470,000 Polish zloty only to repair its locomotives that were damaged in animal-related incidents (i.e. the amount does not include infrastructure repairs). In the first quarter of 2015, costs incurred by the operator in repairing the ED250 (*Pendolino*) trains approximated 200,000 Polish zloty.

AXTONE

AXTONE Group pioneers innovative crash energy absorption solutions targeted at all types of rail vehicles. The company has developed and patented the advanced Crash technology based on permanent plastic deformation of a piece of metal that is sheared out of the outer surface of buffer body. The technology was first employed in buffer manufacture in 2005. It helps mitigate the impact of low-speed collisions by intercepting and absorbing much of the arising energy. It thus addresses passive safety in rail transport, helping protect people, goods and vehicles. The original Polish elastomer technologies and Crash solutions have already gained visibility with customers throughout the world.

Conclusions

The idea of smart, integrated and green transport has been inscribed in EU transport policy and is pursued through such priority initiatives as In2Rail, IT2Rail or Shift2Rail. Innovative rail transport plays an important role in the overarching innovation process and is currently focused on intermodality of both freight transport and public passenger transport. Some of the new technologies introduced in the rail sector are adapted from, or based on, solutions previously implemented in other industry sectors.

Innovative products, services and processes designed and implemented by leading Polish manufacturers have established a presence in a number of markets. The modular locomotive families developed by PESA and NEWAG enable these companies to offer multi-variant products that can satisfy the needs of operators in different segments of the rail market. Track Tec's cutting edge solutions combine product, service and process innovations to epitomize the conceptions of innovation chain and innovation diffusion in the transport sector. The globally unique UOZ-1 devices supplied by NEEL represent a ground-breaking Polish technology that increases safety in rail traffic while at the same time embodying true concern for natural environment. Axtone is a global leader in crashworthy systems that are relevant to passive safety in rail transport, protecting people, goods and vehicles traveling on rail. Bombardier Transportation ZWUS (signalling systems), Medcom (electrical subsystems) and EC Engineering (design) are further examples of Polish companies that have become vital elements of the rail industry's chain of innovation.

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INDUSTRIAL POLICY AND FEATURES OF INDUSTRIAL DEVELOPMENT IN COUNTRIES BELONGING TO INTEGRATION ASSOCIATIONS – THE EUROPEAN UNION AND THE CUSTOMS UNION

Abstract

The article investigates the features of industrial development in countries belonging to integration associations — the European Union and the Customs Union, as well as the policy to support industrial development carried out in them, its targets, mechanisms and instruments. The study is based on analyzing the input-output tables for 38 countries, covering the period of 1995–2011. There have been analyzed: the dynamics of global production, growth rate of output and structure of industrial products in EU and CU countries, share of industry in the economy, growth rate of output and structure of industrial exports, export orientation of industrial production, growth rate of the internal market capacity and consumption structure of industrial products, growth rate of GDP of high-tech industries and share of high-tech industries in industrial GDP. There have been ranked: 20 EU and CU member countries — the largest manufacturers of industrial products, largest exporters and importers of industrial products, 20 countries leading in capacity of the internal market for industrial products, 20 EU and CU member countries with the highest level of import dependence of the internal market for industrial products, 20 EU and CU member countries leading in terms of GDP of high-tech industries. Basic features of the industrial policy in European Union countries as well as in CU member countries have been studied, their differences and weaknesses defined.

Key words

industry, industrial policy, industrial production, the European Union, the Customs Union, high-tech industries

Introduction

The development of the world economy during the past decade is characterized by gradual growth hindered only in crisis years. And it is the industrial sector that played a special role in ensuring the economic security of both individual countries and their associations (the European Union (EU) and the Customs Union (CU). So, today it is difficult to overestimate the importance of industry in the economic development of many leading countries of the world because it is industry that ensures a multiplicative effect in economy as a whole shaping demand for raw materials, energy resources, labor force, creating the largest volumes of value added.

The **aim of the article** is to prove a hypothesis that a sustainable development of economy is characteristic to those countries that carry out an active industrial policy and retain a high share of industry in their economy.

Materials and methods

The information basis of the research is data of input-output tables for the period of 1995 – 2011 [1] on 27 countries of the world, which are full-fledged members of integration associations - the EU and the CU (the acronym “CU” refers to the customs union among Eurasian countries). The study is restricted by 2011 due to a corresponding periodicity of formation and publication of input-output tables in countries of the world. General scientific methods make up a methodological foundation of the research. They include: description, comparison, statistics review, system analysis and others, which help characterize this phenomenon development in a more comprehensive way. For the purposes of the given study the methods of dialectic cognition, structural analysis and logic principles that provide for making authentic conclusions as regards the investigated topic were applied.

Results and discussion

The analysis of main trends of industrial development for the past decades [2-5] indicates that during this period an unstable tendency for production increase with a gradual decrease of its rate was observed in the world. Thus, from 2006 to 2014 the rate decreased from 4.1 to 2.7% (Table 1).

Table 1. Dynamics of the world production for the period of 2006–2014, %

Region	**Year**								
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
World total	4.1	4.0	1.5	-2.1	4.1	2.8	2.3	2.3	2.7
Developed countries	2.8	2.5	0.0	-3.7	2.6	1.4	1.1	1.3	1.8
Developing countries	7.7	8.0	5.4	2.6	7.8	6.0	4.7	4.6	4.7

Source: [6, 7]

During this period, the average annual increase in the world production amounted to 2.4%, including developed countries – 1.1% and developing countries – 5.7%.

The production development had unstable rates in integration associations of the EU and the CU. Thus, for the EU its average annual growth rate amounted to 0.8% in 2006–2014, while for the CU the average industrial production index amounted to 1.6% in 2008–2014 [6, 7].

The analysis of industrial development on the basis of the input-output tables, covering the period of 1995–2011 for countries belonging to the integration associations of the EU and the CU indicates more dynamic development of the latter (Fig. 1).

Fig. 1. Growth rate of industrial output 1 – world; 2 – EU countries; 3 – CU countries
Source: Author's (calculated on the basis of the data [1])

As can be seen from Fig. 1, a significant advantage in the growth rate of industrial output of CU member countries continued throughout the analyzed period. Thus, the average growth rate of industrial output during the period of 1995-2011 amounted to 115.26% in the CU, while it amounted to 104.43% in the EU.

The long-term preservation of a relatively low growth rate of industrial output in EU countries resulted in decrease of their share in the structure of the world industrial output by 9.38% (Fig. 2–3). A considerable increase in the share of countries that are not participants of the considered integration associations (the EU and the CU) also should be noted.

A considerable advantage in the industrial output growth of CU countries can be explained by a high level of absolute indicators of industrial output of EU member countries. By the results of 2011 the list of the largest manufacturers of industrial products among countries participating in the integration associations includes 18 EU countries (Table 2).

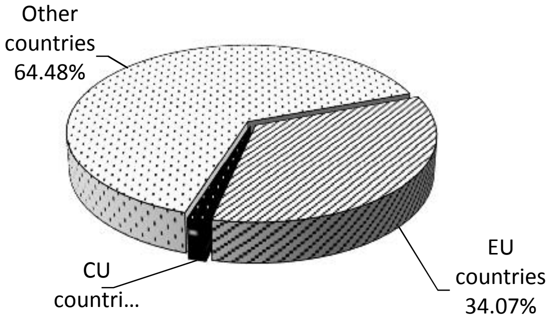

Fig. 2. Structure of industrial production in 1995

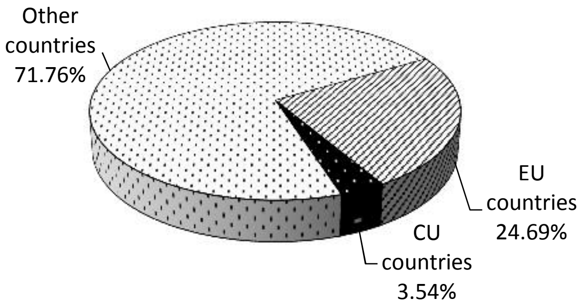

Fig. 3. Structure of industrial production in 2011

Source: Author's (calculated on the basis of the data [1])

Table 2. Ranking of 20 EU and CU member countries – the largest industrial manufacturers

Country	**1995**		**2000**		**2005**		**2011**	
	Production output, mln USD	**Rank**	**Production output, mln USD**	**Rank**	**Production output, mln USD**	**Rank**	**Production output, mln USD**	**Rank**
EU countries								
Germany	1 539 174	1	1 251 774	1	1 907 442	1	2 644 505	1
Italy	807 300	3	789 363	2	1 194 089	2	1 411 822	2
France	855 336	2	757 404	3	1 087 188	3	1 407 738	3
Great Britain	709 194	4	753 881	4	957 767	4	965 887	5
Spain	395 025	5	379 392	5	667 231	5	858 637	6
Netherlands	259 936	6	229 188	6	354 519	7	531 750	7
Poland	103 880	11	118 246	10	227 754	10	409 720	8
Belgium	200 236	8	172 445	8	249 907	8	344 403	9
Sweden	162 106	9	165 166	9	235 242	9	339 331	10
Austria	127 621	10	106 795	11	184 800	11	289 821	11
Czech Republic	57 684	15	63 508	16	141 261	13	244 190	12
Finland	96 823	12	96 970	12	140 306	14	186 208	13
Ireland	55 620	16	91 004	13	143 433	12	185 400	14
Hungary	36 099	19	48 126	17	96 564	17	141 498	15
Denmark	84 850	13	73 639	14	113 926	15	141 013	16
Romania	36 386	18	30 508	19	73 868	19	132 427	17
Portugal	76 757	14	69 387	15	103 593	16	128 656	18
Greece	54 085	17	46 659	18	81 019	18	91 833	20
CU countries								
Russia	242 894	7	184 937	7	549 708	6	1 330 425	4
Kazakhstan	No data	-	No data	-	50 943	20	128 372	19

Source: Author's (calculated on the basis of the data [1])

The most intensive growth of industrial production among the considered countries took place in Russia (by 5.5 times), Czech Republic (by 4.2 times) and Poland (by 3.9 times). However, even taking into account more than a fivefold increase of the industrial output in Russia in 2011, this indicator was twice less than the corresponding indicator of the largest European manufacturer – Germany. Also a significant increase in the industrial output of Belarus, which ranked 22 with the production output of 71 462 mln USD in 2011, is worth mentioning.

The level of significance of industrial production in the economies of CU countries is considerably higher than the corresponding average indicator for all world countries and the level of EU countries as well (Fig. 4). The decrease of this indicator during the crisis in the global economy should be noted. The average value of the share of industry in the economy of EU countries amounted to 32.5% versus 39.9% in CU countries for the period of 1995–2011.

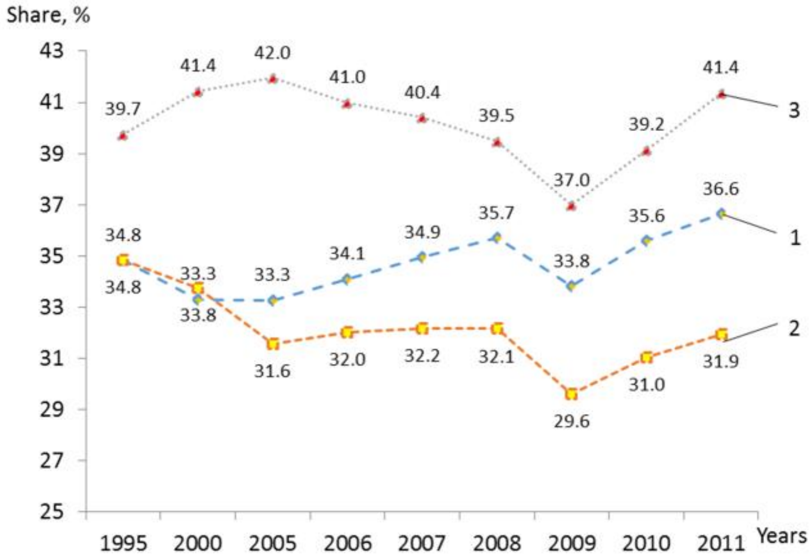

Fig. 4. Share of industry in the economy: 1 – world; 2 – EU countries; 3 – CU countries
Source: Author's (calculated on the basis of the data [1])

A considerable difference in the industrial development of the EU and the CU is observed in terms of the growth rate of industrial exports (Fig. 5).

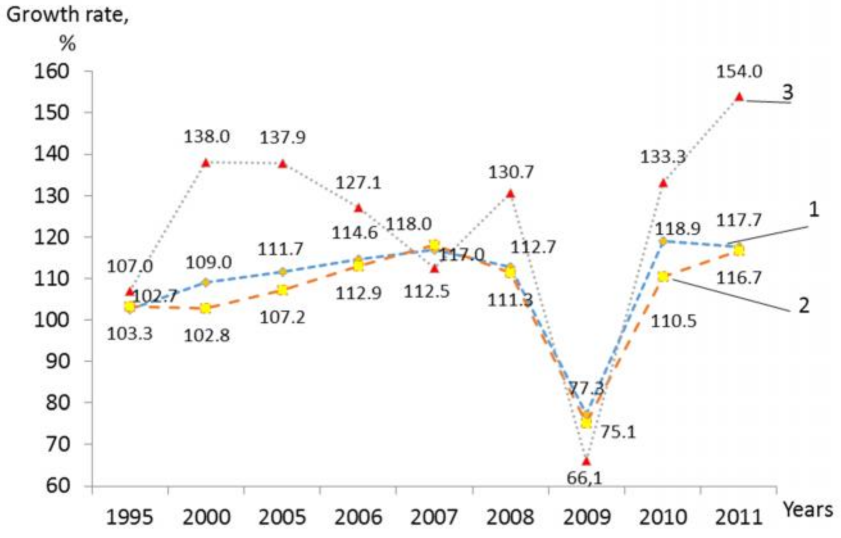

Fig. 5. Growth rate of industrial exports: 1 – world; 2 – EU countries; 3 – CU countries
Source: Author's (calculated on the basis of the data [1])

The increase in the volume of industrial exports in the EU took place at a slow rate — in line with the global trends.

The world market conditions after the crisis period were more favorable for countries of the CU, which allowed increasing the volume of industrial exports by 133.3% and 154.0% in 2010 and 2011 respectively. At the same time decrease of this indicator in 2009: 33.9 % versus 24.9 % in the EU, is more noticeable in comparison with the EU. Preserving the high growth rate of the industrial exports ensured an increase in the share of CU countries in the total world volume from 1.34 % in 1995 to 3.71 % in 2011 (Fig. 6–7).

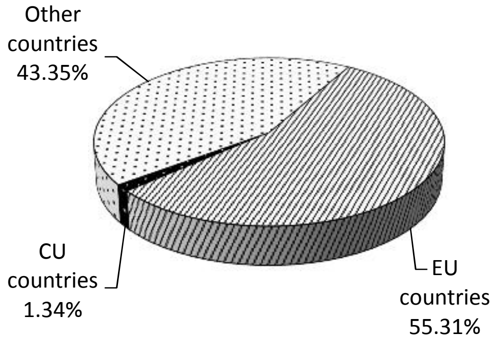

Fig. 6. Structure of industrial exports in 1995

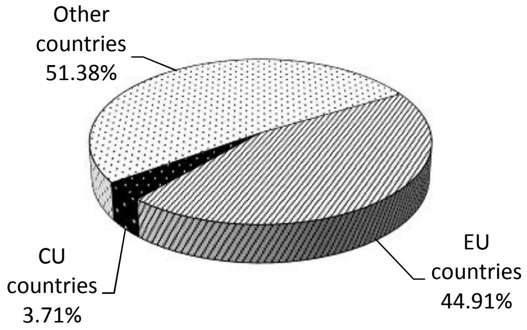

Fig. 7. Structure of industrial exports in 2011

Source: Author's (calculated on the basis of the data [1])

It should be mentioned that more than half of the world industrial exports in 1995 was concentrated in EU countries. As of 2011 the value of the indicator was significantly smaller, but high enough, given the high growth rate of exports of CU countries and third countries. The ranking of EU and CU member countries — the largest exporters of industrial products during 1995–2011 did not undergo noticeable changes (Table 3).

Table 3. Ranking of 20 EU and CU member countries – the largest exporters of industrial products

Country	**1995**		**2000**		**2005**		**2011**	
	Volume of exports, mln USD	**Rank**	**Volume of exports, mln USD**	**Rank**	**Volume of exports, mln USD**	**Rank**	**Volume of exports, mln USD**	**Rank**
EU countries								
Germany	515 529	1	539 789	1	960 309	1	1 391 659	1
France	265 943	2	288 848	2	424 465	2	560 771	2
Italy	220 087	4	227 054	4	352 823	3	496 038	3
Great Britain	241 901	3	278 441	3	348 919	4	437 236	4
Netherlands	153 436	5	146 228	5	229 250	5	376 515	5
Spain	86 802	7	108 512	7	184 840	7	289 146	7
Belgium	136 074	6	121 360	6	188 209	6	268 502	8
Poland	25 649	14	34 532	14	91 402	12	182 155	9
Sweden	78 775	8	86 967	8	128 613	9	178 534	10
Austria	48 533	10	56 045	11	104 921	10	153 826	11
Czech Republic	17 629	16	26 544	15	72 845	13	140 033	12
Ireland	40 591	12	69 650	9	102 774	11	119 223	13
Denmark	50 233	9	45 769	12	71 686	14	93 444	14
Hungary	9 015	17	22 573	17	51 369	16	84 449	15
Finland	39 504	13	45 514	13	66 880	15	83 937	16
Slovakia	7 560	19	10 980	18	28 542	18	51691	18
Portugal	21 759	15	22 610	16	34 468	17	40 407	20
CU countries								
Russia	48 256	11	58 654	10	141 680	8	299 490	6
Kazakhstan	-	-	-	-	23 113	19	72 185	17
Belarus	-	-	-	-	-	-	45 709	19

Source: Author's (calculated on the basis of the data [1])

The largest exporters of industrial products among the above mentioned list of countries during the whole analyzed period remained Germany, France, Italy and Great Britain. More than a sixfold increase in industrial exports in Russia contributed to its moving from the 11th to the 6th position in the ranking. Noteworthy is the fact that the top positions in the ranking of exporters of industrial products are occupied by the countries leading in terms of the largest production output. At the same time the increase in industrial production is largely oriented towards export of products to foreign markets.

Quite a high level of saturation of internal markets for industrial products in European countries contributes to export orientation of their industrial production (Fig. 8).

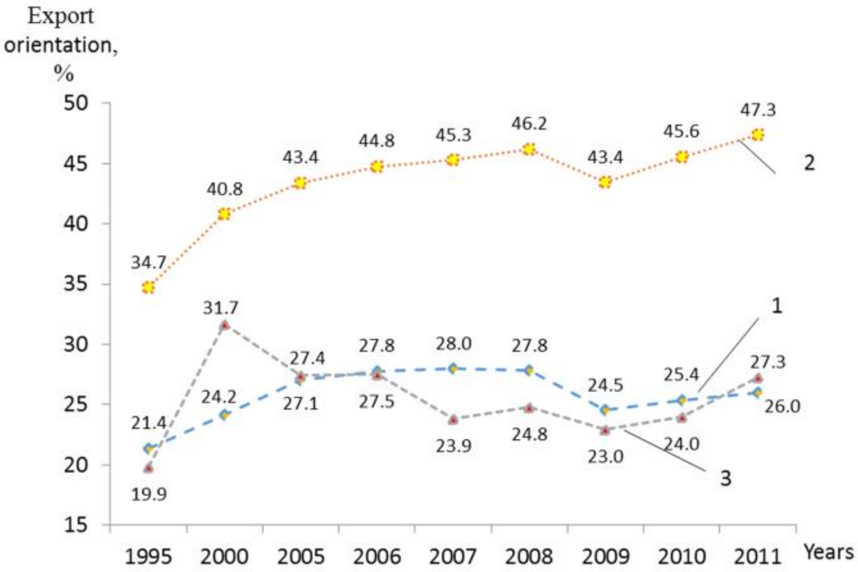

Fig. 8. Export orientation of industrial production: 1 – world; 2 – EU countries; 3 – CU countries

Source: Author's (calculated on the basis of the data [1])

The data presented in Fig. 8 indicate the presence of a stable tendency for growth in export orientation of industrial production in EU countries. By the results of 2011 almost half of the industrial products in these countries was realized in foreign markets. This testifies to the growth of their dependence on external factors.

However, it should also be taken into account that a substantial part of exports is carried out within the common market of EU countries. The indicator of export orientation of industrial production in CU member countries is almost twice lower than that of the EU. There can be observed the dynamics of its decrease during 2000–2010 and a significant increase in 2011.

Unlike European countries, the industrial development of CU member countries occurs at the expense of their internal markets. Considerably higher, compared to EU countries, level of capacity of the internal market for industrial products can be observed during the entire study period (Fig. 9).

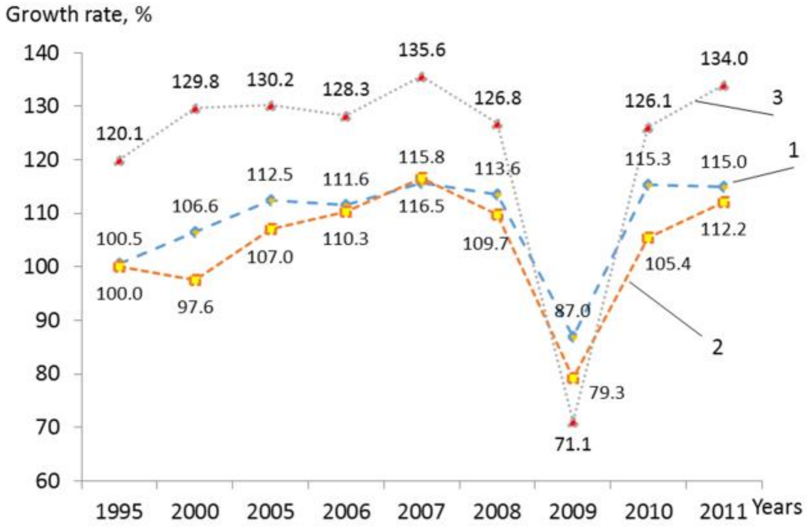

Fig. 9. Growth rate of capacity of the internal market for industrial products: 1 – world; 2 – EU countries; 3 – CU countries

Source: Author's (calculated on the basis of the data [1])

A significant decrease of this indicator in EU countries occurred during the crisis for these countries period of 1998–1999 (by 24.5% and 43.0% respectively) and the global crisis (28.9%). The average growth rate of capacity of the CU internal market for industrial products for 1995–2011 amounted to 115.3%. The value of the respective indicator for EU countries amounted only to 104.6 %, which gives grounds to speak about a low intensity of development of their internal markets. For comparison, the average growth rate in the world over the same period amounted to 106.6%.

The structure of consumption of industrial products underwent significant changes in 2011 compared to 1995 (Fig. 10–11).

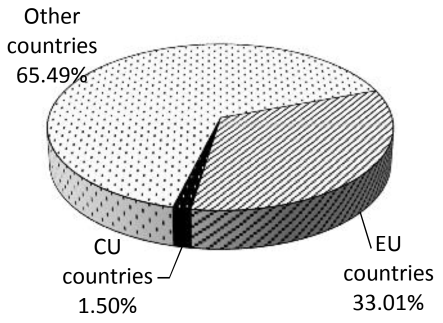

Fig. 10. Structure of consumption of industrial products in 1995

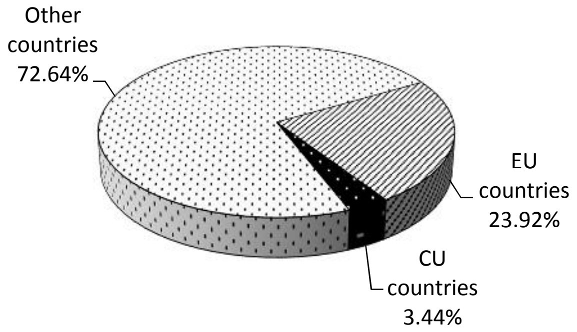

Fig. 11. Structure of consumption of industrial products in 2011

Source: Author's (calculated on the basis of the data [1])

Unlike EU countries, which share in the structure of the world consumption of industrial products significantly decreased (by 9.1 %), the share of CU countries increased by 2.3 times. The main reason of the decrease in the EU share is a significant increase in consumption of industrial products in third countries, which are not participants of the analyzed integration associations.

Considering a relatively low growth rate of capacity of internal markets for industrial products, EU countries hold top positions in the ranking of 20 countries leading in terms of this indicator during 1995–2011 (Table 4).

Table 4. Ranking of 20 countries leading in terms of capacity of the internal market for industrial products

Country	**1995**		**2000**		**2005**		**2011**	
	Capacity of the internal market, mln USD	**Rank**	**Capacity of the internal market, mln USD**	**Rank**	**Capacity of the internal market, mln USD**	**Rank**	**Capacity of the internal market, mln USD**	**Rank**
EU countries								
Germany	1 431 968	1	1 155 340	1	1 651 907	1	2 328 836	1
France	832 889	2	744 211	4	1 094 696	3	1 472 308	2
Italy	768 862	3	775 571	2	1 185 657	2	1 411 923	3
Great Britain	701 809	4	775 414	3	1 031 868	4	1 067 591	5
Spain	409 329	5	414 258	5	746 633	5	904 632	6
Netherlands	233 647	7	205 243	6	299 389	7	446 672	7
Poland	100 349	11	126 756	10	225 323	9	407 481	8
Belgium	183 577	8	163 807	8	237 002	8	339 476	9
Sweden	139 186	9	141 589	9	202 000	10	306 326	10
Austria	134 004	10	108 824	11	181 440	11	289 866	11
Czech Republic	60 803	16	65 406	16	135 925	12	227 653	12
Finland	82 042	13	79 047	13	121 912	15	171 321	13
Romania	38 803	19	34 156	19	87 874	19	154 645	14
Portugal	82 888	12	81 977	12	123 617	14	150 251	15
Greece	72 245	15	70 834	14	124 583	13	143 088	16

Country	1995		2000		2005		2011	
	Capacity of the internal market, mln USD	Rank	Capacity of the internal market, mln USD	Rank	Capacity of the internal market, mln USD	Rank	Capacity of the internal market, mln USD	Rank
Hungary	40 539	18	52 956	18	103 335	17	140 361	17
Denmark	78 162	14	66 757	15	106 054	16	132 392	18
Ireland	41 808	17	62 775	17	102 866	18	125 685	19
CU countries								
Russia	249 009	6	167 401	7	522 726	6	1 336 818	4
Kazakhstan	-	-	-	-	45 559	21	96 345	20

Source: Author's (calculated on the basis of the data [1])

Having a developed internal market helps reduce dependence on conditions in the international market for industrial products. The leaders of the presented ranking are also EU countries: Germany, France and Italy. A significant increase in the capacity of the internal market of Russia allowed it occupying the 4th position in the ranking. In general, by the results of 2011, the capacity of the internal market of EU countries was sevenfold higher than the corresponding figure for CU countries.

Along with a substantial level of export orientation of industry in EU countries, a considerable volume of imports of corresponding products to these countries should be mentioned. The list of twenty countries — the largest importers of industrial products for the period of 1995–2011, did not undergo significant changes (Table 5).

Table 5. Ranking of 20 EU and CU member countries — the largest importers of industrial products

Country	1995		2000		2005		2011	
	Volume of imports, mln USD	Rank	Volume of imports, mln USD	Rank	Volume of imports, mln USD	Rank	Volume of imports, mln USD	Rank
EU countries								
Germany	408 323	1	443 356	1	704 774	1	1 075 990	1
France	243 496	2	275 655	3	431 974	2	625 341	2
Great Britain	234 516	3	299 974	2	423 020	3	538 940	3
Italy	181 649	4	213 262	4	344 390	4	496 139	4
Spain	101 106	7	143 378	5	264 242	5	335 141	5
Netherlands	127 147	5	122 283	6	174 120	7	291 437	7
Belgium	119 415	6	112 722	7	175 304	6	263 575	8
Poland	22 118	16	43 042	10	88 970	11	179 916	9
Austria	54 915	9	58 074	9	101 561	9	153 870	10
Sweden	55 855	8	63 391	8	95 371	10	145 529	11
Czech Republic	20 747	17	28 443	16	67 509	12	123 497	12
Denmark	43 546	11	38 888	13	63 813	13	84 824	13
Hungary	13 455	18	27 403	18	58 139	15	83 311	14
Finland	24 723	14	27 591	17	48 486	18	69 050	15
Greece	22 570	15	29 312	15	52 323	17	63 028	16
Portugal	27 890	12	35 201	14	54 492	16	62 002	17
Ireland	26 779	13	41 421	11	62 208	14	59 507	18
Romania	8 976	19	11 533	19	35 317	19	55 470	19
Slovakia	7 512	21	10 772	20	29 821	20	50 040	20

Country	1995		2000		2005		2011	
	Volume of imports, mln USD	Rank	Volume of imports, mln USD	Rank	Volume of imports, mln USD	Rank	Volume of imports, mln USD	Rank
CU countries								
Russia	54 371	10	41 118	12	114 698	8	305 883	6

Source: Author's (calculated on the basis of the data [1])

As can be seen from Table 5, the highest rate of increasing the volume of industrial imports for the period from 1995 to 2011 is observed in Poland (by 8.1 times), Slovakia (by 6.7 times), Hungary and Romania (by 6.2 times). More than a fivefold increase in the volume of industrial imports took place in Russia, which ensured the country's moving from the 10th to the 6th position in the ranking. Other countries participating in the CU — Belarus and Kazakhstan — occupied, respectively, the 21th and the 22nd positions in 2011. The total import of CU countries is almost by fourteen times lower than the corresponding figure for EU countries.

The consequence of the rapid growth in the volume of industrial imports to EU countries was increase in their import dependence from 32.1% in 2005 to 46.5% in 2011. Unlike the EU, the growth in the share of imports in the total volume of consumption of industrial products of CU countries was significantly lower (from 21.8% to 24.2% for the corresponding period). It is worth noting that the growth of the import dependence indicator took place in all EU countries except Ireland. The ranking of 20 EU and CU member countries with the highest level of import dependence of the internal market by the results of 2011 is presented in Table 6.

Table 6. Ranking of 20 EU and CU member countries with the highest level of import dependence of the internal market for industrial products

Country	1995		2000		2005		2011	
	Import dependence, %	Rank	Import dependence, %	Rank	Import dependence, %	Rank	Import dependence, %	Rank
EU countries								
Belgium	65.05	1	68.81	1	73.97	1	77.64	1
Netherlands	54.42	5	59.58	4	58.16	8	65.25	2
Slovenia	49.66	6	55.81	6	63.01	2	64.20	3
Denmark	55.71	3	58.25	5	60.17	6	64.07	4
Estonia	55.27	4	64.30	3	61.32	3	61.81	6
Hungary	33.19	15	51.75	9	56.26	9	59.36	7
Slovakia	36.96	11	50.78	11	59.08	7	56.24	8
Lithuania	47.74	7	50.99	10	54.06	11	55.79	9
Czech Republic	34.12	12	43.49	14	49.67	12	54.25	10
Latvia	46.14	8	55.36	7	60.48	4	54.15	11
Austria	40.98	9	53.36	8	55.98	10	53.08	12
Great Britain	33.42	14	38.69	17	41.00	18	50.48	13
Sweden	40.13	10	44.77	13	47.21	13	47.51	14
Ireland	64.05	2	65.98	2	60.47	5	47.35	15
Germany	28.51	20	38,37	18	42.66	16	46.20	16
Poland	22.04	24	33.96	22	39.49	21	44.15	17
Bulgaria	31.28	16	47.94	12	46.04	14	44.09	18
Greece	31.24	17	41.38	16	42.00	17	44.05	19
France	29.24	19	37.04	19	39.46	22	42.47	20

Country	1995		2000		2005		2011	
	Import dependence, %	Rank	Import dependence, %	Rank	Import dependence, %	Rank	Import dependence, %	Rank
CU countries								
Belarus	-	-	-	-		-	63.53	5

Source: Author's (calculated on the basis of the data [1])

As can be seen from Table 6, the lowest level of import dependence of the internal market for industrial products among all EU and CU member countries in 2011 was observed in Russia (22.9%). In general, it can be argued that the market share of industrial imports of CU countries is lower than that of the EU, with the difference in values of these parameters having a stable tendency to growth. However, this quite a significant import dependence in the EU countries can be explained by the fact that they sell a large share of their products in the common market of the Community.

Restrictions of economic cooperation with CU countries (primarily Russia) negatively affect their investment climate, exchange of experience and technology with EU countries. However, the development of high-tech industries of CU member countries during the period of 1995-2011 occurred at a considerably higher rate compared to the EU (Fig. 12). During the period of 1995–2011 the average GDP growth of high-tech industries in EU countries amounted to 103.7%, and in the countries of CU – 112.8%. There should be mentioned a sharp decline in this indicator for both of the studied integration associations, which occurred in the crisis year of 2009. The period of recovery after the crisis is characterized by a significant predominance in GDP growth of high-tech industries of the CU.

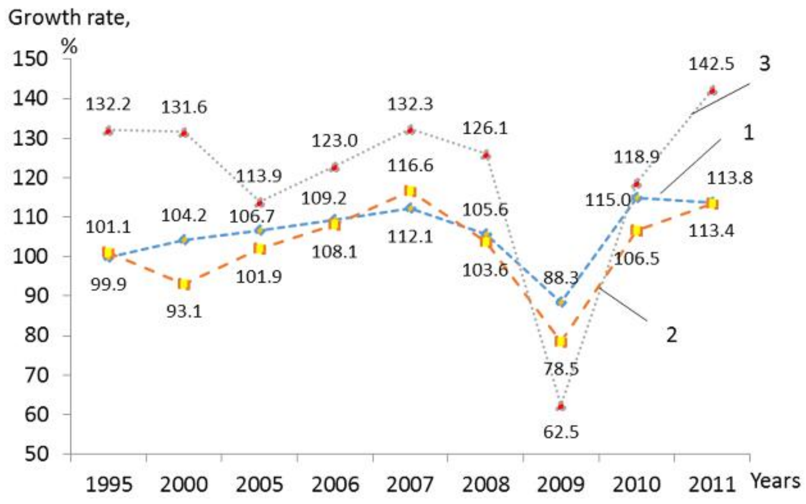

Fig. 12. GDP growth rate of high-tech industries: 1 – world; 2 – EU countries;
3 – CU countries

Source: Author's (calculated on the basis of the data [1])

GDP growth of high-tech industries of CU countries is going at a lower rate compared to other industries. This is confirmed by the reduction in GDP share of high-tech industries in GDP of CU countries for 1995–2011 (Fig. 13). The low level of this indicator as compared to EU countries and the average level of all the world countries should also be noted.

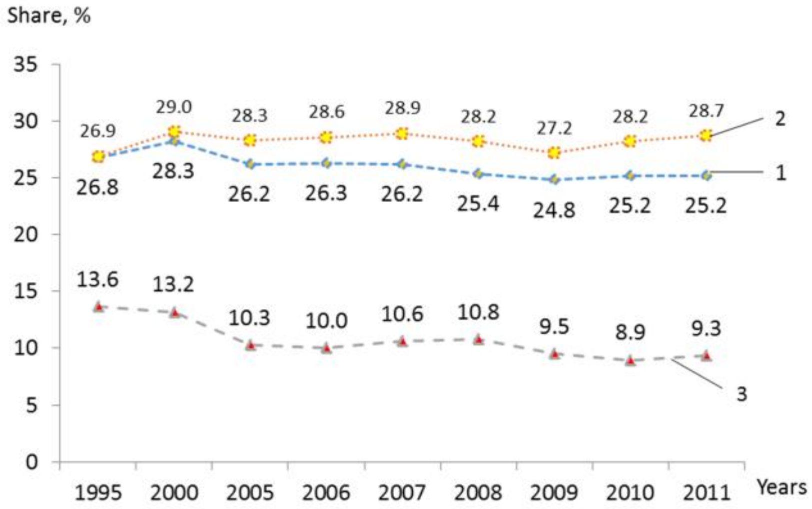

Fig. 13. GDP share of high-tech industries in industrial GDP: 1 – world; 2 – EU countries;
3 – CU countries
Source: Author's (calculated on the basis of the data [1])

Unlike the CU countries, the dynamics of GDP share of high-tech industries in GDP of EU member countries was more stable. The average level of this indicator in the EU for the period of 1995-2011 was 28.3% (in the CU — 12.0%) and fell no lower than 26.9%. These data indicate that the industrial development of EU countries is going on with preserving the shares of industries, while the share of the high-tech component of industrial development of CU countries is progressively decreasing.

The ranking of 20 EU and CU member countries leading in terms of GDP volume of high-tech industries by the results of 2011 is presented in Table 7.

Table 7. Ranking of 20 EU and CU member countries leading in terms of GDP volume of high-tech industries

Country	**1995**		**2000**		**2005**		**2011**	
	GDP volume of high-tech industries, mln USD	**Rank**	**GDP volume of high-tech industries, mln USD**	**Rank**	**GDP volume of high-tech industries, mln USD**	**Rank**	**GDP volume of high-tech industries, mln USD**	**Rank**
EU countries								
Germany	211 948	1	171 198	1	264 010	1	360 567	1
Italy	58 635	4	58 789	4	86 433	2	99 056	2
Great Britain	67 789	2	73 945	2	78 097	4	81 307	3
France	65 664	3	62 953	3	79 500	3	80 195	4
Spain	25 074	5	24 181	5	37 298	5	39 551	6
Sweden	17 796	6	18 413	6	25 649	6	32 859	7
Austria	12 092	10	11 052	8	18 259	8	25 326	8
Netherlands	13 725	7	12 773	7	16 539	9	22 915	9
Czech Republic	2 931	15	4 410	15	10 463	13	19 452	10
Poland	5 549	13	6 313	14	12 111	12	16 014	11
Hungary	1 814	18	3 454	16	9 079	15	15 550	12
Finland	8 205	11	10 896	9	15 712	10	14 142	13
Belgium	12 314	9	9 689	10	12 337	11	13 395	14
Denmark	7 929	12	6 626	13	8 882	16	10 760	15
Ireland	4 656	14	8 145	12	10 284	14	10 157	16
Romania	1 926	17	1 366	19	4 527	17	9 622	17

Country	1995		2000		2005		2011	
	GDP volume of high-tech industries, mln USD	Rank	GDP volume of high-tech industries, mln USD	Rank	GDP volume of high-tech industries, mln USD	Rank	GDP volume of high-tech industries, mln USD	Rank
Portugal	2 581	16	3 158	17	4 011	18	5 700	18
Slovakia	908	21	1 157	20	2 830	19	5 636	19
CU countries								
Russia	12 773	8	9 666	11	23 777	7	48 690	5
Belarus	-	-	-	-	-	-	3 777	20

Source: Author's (calculated on the basis of the data [1])

In 2011 the largest GDP volume was observed in EU countries: Germany, Italy, Great Britain and France. Among the participants of the CU Russia (the 5th place) and Belarus (the 20th place) are in the presented ranking. For the period of 1995-2011 the most intensive (more than fivefold) increase in absolute value of GDP volume of high-tech industries occurred in Hungary, the Czech Republic, Slovakia and Romania. Growth of the corresponding value in Russia by 3.8 times ensured its moving from the 8th to the 5th position in the ranking.

The conducted analysis of the dynamics of industrial development in the integration associations revealed a significant advantage of EU countries. To the list of the most developed EU member countries there can be included Germany, Italy, France and Great Britain. It is these countries that during the whole analyzed period occupied the top positions in the rankings in terms of production output, internal market capacity, industrial exports. CU member countries are behind EU countries in terms of all the indicators but demonstrate a higher rate of development.

One of the key differences in industrial development of CU member countries is their orientation towards the internal market and a low level of import dependence, which indicates their relatively low level of integration into the world market for industrial products. At the same time, the internal markets for industrial products of EU countries are more open and the production development occurs at the expense of foreign markets. This, in its turn, increases dependence of EU countries on external factors. The advantage of EU countries in the world market for industrial products is ensured at the expense of high-tech production.

Consequently, the above mentioned tendencies indicate recovery of the trend of state support for industry both in EU and CU countries because recently it is industrial development that has been considered by the academics and practitioners as a basis for sustainable socio-economic development of the country. At the same time the features and achieved level of development of EU and CU countries are reflected in industrial policies carried out in them.

In recent years the EU has been paying great attention to industrial policy. The European Parliament adopted a number of resolutions to strengthen the industrial policy. The economic strategy "Europe 2020" aimed at economic growth and creating new jobs has been approved. The implementation of a new program "Horizon 2020", which combines the framework programs on research and development of competitiveness and innovations, has been started. Table 8 presents a brief characteristic of the essence and features of industrial policy in individual countries of the European Union.

Table 8. Features of industrial policy in individual countries of the European Union

Country	Features of industrial policy
Germany	Increasing attention to using selective measures in the direction of achieving one or two goals in a certain industry. Development of key technologies and manufactures in the energy sector (renewable and nuclear safety); environment, nano- and biotechnology, etc. [8].
France	Increasing attention to industrial policy: – creation of the innovation agency and mobilization of financial resources for the

Country	Features of industrial policy
	development of five major sectors of economy: energy, transport, information technology, environment protection, health care [9] in 2005; – establishment of the Fund of Strategic Investment (FSI) in 2008 of 35 mlrd. EUR to support growing business and stimulating the country's exit from the recession; – focus on the commercial conversion of scientific developments of universities and the need to support such priority sectors as digital technologies, nano- and biotechnologies, renewable energy sources, environmentally friendly cars, etc. [10].
Great Britain	Increasing attention to industrial policy in 2008-2009: – establishment of the Fund of Strategic Investment to support innovations; – preserving and increasing the number of jobs; – development of energy efficient technologies; – development of manufacturing industry and digital infrastructure; – supporting export of products [11].

Source: Author's (compiled on the basis of the data [8–11])

Based on of the above mentioned it can be concluded that the main purpose of state support of industrial development in the EU is to make the European economy the most competitive and dynamic in the world. The industrial policy of the leading countries – EU members (Germany, UK) can be defined as a policy to support knowledge-intensive and high-tech industries. The general conclusion to be drawn with regard to the practice of implementing industrial policy in EU countries is dominance of a comprehensive approach to the selection of both development priorities (knowledge-intensive and high-tech industries) and its implementation instruments (creation of strategic investment funds, etc.).

Strategy 2020 demonstrates the undeniable evolution in the approach of the European Commission to the development of the industrial sector in the EU, but so far not all member countries of the Community have implemented the "new approach" to industrial policy in their strategic documents and are not fully prepared to participate in new programs and projects.

CU member countries also pay great attention to the development of industry, which is testified by the elaborated concepts, strategies and regulations as well as the approved national programs. However, the set goals in some degree differ from the strategic guidelines of industrial development in EU countries.

The main strategic goals of industrial development of Russia, Belarus and Kazakhstan are as follows:

- ensuring structural changes in favor of manufacturing and processing sectors;

- development of manufactures belonging to "breakthrough" areas of higher technological paradigm;

- import substitution in the industrial sectors, providing technological and environmental safety, etc.

The analysis of the existing national programs of Russia, Belarus and Kazakhstan in the field of industry indicates that they have a high degree of convergence in the part concerning the development methodology, industrial development issues, goals and objectives, instruments and mechanisms of implementing the state policy in the field of industry. But they lack coordination of the national industrial policies with the mechanisms of deeper industrial cooperation with the prospect of carrying out a coherent industrial policy in key sectors.

In each of the countries the objectives on increasing the volume of production output and exports according to the similar sectoral priorities are set, with no focus on the formation of a common internal market within the CU considering specialization of the countries by certain types of products. An important problem of implementing national industrial programs within the CU is the lack of coordination. The CU member states consider internal markets of each other from the standpoint of available and spacious export market, while their national internal markets are intended by them for import substitution by their products. Exports of goods from Russia, Belarus and Kazakhstan to other countries has a high degree of intersection that leads to unjustified competition between CU member countries, and, taking into account the priority of relevant sectors and exercised government support — to strengthening the contradictions between them.

Summary and conclusions

1. The main differences of the industrial development in countries belonging to the integration associations of the EU and CU are as follows:

a) the development of industry in the integration associations of the EU and the CU, as well as in the whole world, had an unstable rate. However, if the average annual growth rate amounted to 0.8% in the EU in 2006–2014, the average index of industrial production in the CU in 2008–2014 amounted to 1.6%;

b) the detailed analysis of the development of industry according to the input-output tables for the period of 1995–2011 by countries belonging to the integration associations of the EU and the CU indicates more dynamic development of the latter. Thus, for the analyzed period the industrial GDP in the CU member countries increased by 593.5% versus 155.2% in the EU member countries and exports of industrial products increased respectively by 772.9% and 294.5%;

c) GDP of high-tech industries in the CU also had a higher growth rate — 401.3% compared to the EU member countries — 166.0%, while by the share of high-tech industries the EU member countries continue leading — 28.7% vs. 9.0% in the CU;

d) one of the key differences in industrial development of CU countries is their orientation towards the internal market and low level of import dependence indicating a relatively low level of integration into the global market of industrial products. At the same time, internal markets for industrial products in EU countries are more open, and the production development occurs at the expense of external markets. This, in turn, increases the dependence of EU countries from external factors. The advantage of EU countries in the international market for industrial products is ensured by high-tech manufacturing. So, over the analyzed period the industry in CU member countries developed more dynamically than in EU member countries. But in terms of the level of industrial structure progressivity EU member countries continue to be considerable ahead of CU countries.

In general, the conducted analysis revealed a significant advantage of the EU countries over the countries of the CU in the development of their industry. The list of the most industrially developed EU countries includes Germany, Italy, France and the UK. It is these countries that during the whole period of the study occupied leading positions in the rankings in terms of production output, capacity of internal markets, export of industrial production. The countries of the CU fall behind the EU countries in terms of all absolute indicators, while demonstrating a higher growth rates.

2. A considerable increase in the share of knowledge-intensive industries in manufacturing of innovative products has become a distinctive feature of the development of the modern world industrial complex.

3. In recent years, much attention has been paid to the industrial policy both in EU and CU countries. However, if the EU applies a comprehensive approach to the selection of both development priorities (knowledge-intensive and high-tech industries) and instruments of its implementation, in CU countries there observed lack of coordination of the industrial policies in the countries, their insufficient elaboration, lack of effective implementation mechanisms, which practically does not allow to ensure effective industrial development and competitiveness of its products in foreign markets.

4. The comparative analysis of the industrial development in the countries of the EU and the CU allowed proving that a sustainable development of economy is characteristic to those countries that carry out an active industrial policy and retain a high share of industry in their economy. At the same time the industrial policy of the countries has its peculiarities and differences specified by conditions and priorities of their development.

During the years that passed after conducting by the authors the fundamental research of the development of industry for 27 countries of the world, which are full-fledged members of integration associations — the EU and the CU - for the period of 1995 – 2011, in the world economy there occurred changes that have already affected and will continue affecting its development. For example, there took place events that influenced the economy of such a significant CU member country as Russia. These are the drop in world oil prices and sanctions of the international community in response to the Russian aggression in Ukraine. The changes in the Russian economy, in turn, can influence the development of economies of a number of other countries in a certain way. Also, in the authors' opinion, one of the factors that are already beginning to affect the development of economies of countries of the world (including those belonging to the EU and the CU) is the slowdown of the economic growth of China. Therefore, the authors see prospects for further research in conducting a similar analysis of the development of industry and industrial policy in the EU and CU countries on the basis of the presented approach in the succeeding period, which should reflect the impact of the mentioned (and other) factors and global macroeconomic conditions on the development of economies of the countries and define effective areas of their growth in the future.

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RENEWABLE ENERGY IN PLANNING OF SUSTAINABLE URBAN UNITS, IS ENERGY AUTARKY POSSIBLE IN NZEB BUILDINGS?

Abstract

Energy autarky is a concept commonly used in the context the of power off-grid or remote island systems. However, it has rarely reflected the idea of self-sufficiency of urban units, especially in cities with access to external technical infrastructures such as power and district heating networks. Energy autarky can also be considered auxiliary to nZEB calculation procedures, as an energy demand-supply balancing approach for calculating renewable energy shares. In fact, in Central and Eastern Europe for existing urban tissues buildings' self-sufficiency would be difficult to achieve due to a dominating role of space heating in energy demand shares. Proportions can, however, change in nZEB (nearly zero energy) buildings, with increasing importance and shares of electricity in the final energy consumption and a decreasing role of space heat. In this article a new approach to planning of energy (electricity) autarky at the level of an urban unit is presented, taking into account new nZEB standards at the same time. This is supposed to serve as a voice in the discourse on the formulation of future methodologies.

Key words

energy autarky, nZEB, renewable energy, urban unit energy analysis

Energy autarky – general concept

Energy autarky (autonomous energy entity) has been defined in the surveyed literature as a partial or total independence from energy supply networks (electricity, heating and gas) [1]. On the supply side the question is how energy demands can be sustained by clean, renewable energy sources (such as solar energy, biomass, wind, or heat pumps). Energy autarky while focusing mainly on energy efficiency and green energy supply measures (renewables) can also integrate other technological concepts such as smart grids or energy storage, serving to optimize the energy demand-supply balance of an urban unit [2], [3]. The energy autarky concept based on intermittent, weather dependent renewables (such as wind and solar energy, with hourly balancing procedures); additionally has to incorporate energy storage systems. Such solutions have been applied on islands, remote farms in the US, Australia or in countries, where power grid has been underdeveloped (Asia, Africa) [2], [4]. Another niche for autarky systems lies in rural areas with emerging energy cooperatives.

Due to economic reasons European power systems work prevailingly as on-grid systems (connected to the national power grid), due to increasing popularity of individual energy storage (supported also by economic incentives), *e.g.* in Germany [2].

It needs to be stressed that currently achieving even a partial energy autarky for an urban unit would be difficult, although there were numerous attempts undertaken to introduce energy autonomous systems [5]. An example of such is Frederikshavn, a Danish city of 50 thousand inhabitants, where the energy system is based on geothermal, offshore wind, as well as energy from biomass and biowaste. Ambitious targets were subject to computer modeling for regions or even for whole countries such as Ireland, Portugal and Denmark [6]. In total 40 islands all over the world were identified as off-grid semi-autarky systems, *e.g.*: Utsira (Norway), Salina (Italy), Azores (Portugal) or Bornholm (Denmark). However, due to various techno-economic constrains a 100% level of energy autarky (covering energy demands with renewables) has never been reached in real life (usually the outcome was 20-80%) [4].

Energy autarky, renewable energy as a part of nearly zero energy (nZEB) concept

According to the EU legislation a nearly zero energy is a building that "*has a very high energy performance with a low amount of energy required covered to a very significant extent by energy from renewable sources, including energy from renewables produced on-site or nearby*" [7]. The Article 9 of the EPBD recast [7] states that Member States shall ensure that new buildings occupied by public authorities are Nearly Zero Energy Buildings (nZEB) by December 31st 2018 and that new buildings become nZEBs by December 31st 2020. This legislation does not indicate, however, how member states should define the desired high energy performance [1]. For new and retrofitted buildings, energy performance of a building means that the calculated or measured amount of required energy meet the demand associated with a typical use of the building, which includes, *"inter alia, energy used for heating, cooling, ventilation, hot water and lighting"*. The term *inter alia* (among others) indicates that the catalogue of other energy demands is opened. Electricity used for household appliances (e.g. kitchen appliances, laundry equipment, TVs, etc.) is not mandatory under EPBD recast but not excluded as an option from EPBD recast's methodology. It can and should be considered in the future nZEB methodologies as the electricity demand by other household appliances and devices has been steadily growing [8]. This article assumes that nZEB methodologies would change in the future and the presented approach can serve as a voice in the relevant scientific discourse.

On the energy supply side EU member states are free to elaborate their own methodology for calculating renewable energy shares in covering energy demands in nZEB buildings. Poland has been so far very cautiously implementing new requirements. Energy demand targets were set for new and retrofitted buildings, both private and public (Table 1). However, the legislation did not stipulate any means for calculating renewable energy shares. In Poland, unlike in other countries, exact siting options for renewables were not specified (distinction between onsite, nearby and external sites) [1]. The current legislation (latest amendments of 2015) does not refer to the nZEB standard specifically (only energy efficient building are mentioned) [1].

Table 1. Current requirements for new and retrofitted buildings in Poland (EP indicator for space heating, hot water, ventilation)

Type of building		2014	2017	2021*
		EP kWh/(m^2 a)		
Residential buildings	a) single-family housing	120	95	70
	b) multifamily housing	105	85	65
Non-residential buildings		95	85	75
Public buildings	a) health care	390	290	190
	b) others	65	60	45
Warehouse and production buildings		110	90	70

* 2019 for buildings owned by public entities.

Source: [9]

Renewable energy sources integration in the building stock

The majority of buildings in Poland are residential houses, they make up some 5.5 million buildings [10], with 1% of new stock per year. Although residential housing (Table 2) makes the majority of the building stock in Poland, buildings with other functions (Table 3) also need to be considered. 100 thousand buildings in Poland (source: various statistical books of the Central Statistical Office) have a good educational and demonstrational potential for renewable energy integration in the building stock. Additionally, the non-residential sector is characterized with dynamic growth rates (*e.g.* for offices and depots 20% increase annually). The potential in rural areas (Table 2) also cannot be omitted as 40% of the Polish population still live there.

Table 2. Building stock and most typical capacities of renewable micro installations applied in new/retrofitted buildings, in Poland

Building's function	**Number of buildings in 2011**	**Typical installation capacity (kW)**				
Renewable micro installation		**W**	**PV**	**STC**	**HP**	**BB**
Multifamily houses in cities *only in cities <20 thousand inhabitants	0.3 million		30	30	100	120*
Single-family houses in cities and *peri-urban areas only	< 2 million		3	7	10	10*
Residential buildings in rural areas	>3 million	1.5	3	7	10	10
W-wind, **PV**- photovoltaic, **STC**- solar thermal collectors, **HP**-heat pumps, **BB**- biomass boilers						

Source: [10]

Table 2 presents possible power capacities of different renewable micro installations, which can be installed in buildings, with most typical (based on the so-far experience in Poland) power capacities. The application of dispersed renewable energy heating technologies is restricted only to smaller cities and peri-urban areas. In densely populated areas it would not be an economically viable option due to access to district heating networks.

Table 3. Non-residential building stock and most typical capacities of renewable micro installations typically applied in new/retrofitted buildings, in Poland

Building's function	Typical installation capacity (kW)			
Renewable micro installation	**W**	**PV**	**STC**	**HP**
Education: kindergartens, primary schools, secondary schools, universities *etc*.	2	30	35	100
Human health and social work entities, hospitals*, health resorts , medical clinics		15 200*	35 175*	700*
Hotel facilities ** hotels, motels**, guesthouses**, holiday villages, centers for training and recreation, teams, camping sites, camping sites, hostels, health establishments, lodging agritourist, hostels***		30	35	100**
Churches, parish buildings, monasteries		50		30
Commercial buildings, large > $2000m^2$, petrol stations	10	30		150
Arts, entertainment and recreation, cultural centers, museums		15	20	100
Offices, 57% located in Warsaw		15		100
Storage spaces, logistics and warehousing centers	10	100		200
W-wind, PV- photovoltaic, STC- solar thermal collectors, HP-heat pumps, *applied only in chosen buildings				

Source: Author's

Once the correlation between the building function and a micro installation's size is identified, technical parameters for calculating energy production (energy supply) can be assumed. Capacity ranges, capacity utilization rates, final energy use, energy storage options were assumed for the purpose of further analyses, as presented in Table 4.

Table 4. Typical technical parameters of renewable energy micro installations

Renewable micro installation	Capacity range [kW]	Capacity utilization rate [h]	Final energy demand use	Energy storage
Wind	1.5-10	950	EL	
Photovoltaic	3-200	800	EL	yes for off-grid
Biogas and other cogeneration	5-40	7,000	H, HW, EE	
Solar thermal collectors	7-175	630	HW	hot water cylinder
Heat pumps	10-200	4,500	H, HW	
Biomass boilers	20-150	2,200	H, HW	
EL - electricity, H- space heating, HW- hot water				

Source: Author's

Different urban resolutions can be chosen for energy autarky analyses: a household, building, housing estate, block of flats, district, city, region or even a whole country. As a consequence such delimitation results in a higher or lower level of input/output details. At the building level an energy audit procedure would be the best recommended option to calculate the energy standard, currently the most frequent option chosen by the member states to elaborate the methodology required by the EU legislation [7]. Some member states, in fact, have already considered a building site consisting of a group of buildings as the unit to be analyzed under the nZEB procedure [1]. On a zone level an energy audit, however, would be too much detailed; for many buildings it would turn out to be time consuming and superfluous.

Case study analysis

Assumptions

The analysis was performed for a newly designed urban unit of Czerniaków South district, delineated in the capital city of Poland. The urban and architectural design of the area was prepared by SOL-AR company. The analyzed urban unit is located in the south-western part of Warsaw, in the district called Mokotów with the area of 54 ha and planned density of population 163 persons per hectare. The green areas take up 11.7% of the total, the whole urban unit is located in the vicinity of a valuable green belt of the Vistula river, the Czerniakowskie lake nature reserve and a nearby park.

Fig. 3 Conceptual urban design for the analyzed area
Source: K. Solarek, J. Solarek, SOL-AR

The unit consist prevailingly of commercial buildings with 62% of the built-up area and 4.9 hectares followed by multi-family and services with 2.4 hectares and single-family housing with 0.6 hectares (Table 5).

Table 5. Calculation of electricity demands split-up into different building functions

Function	Built-up area (ha)	Number of inhabitants	Electricity energy demands [MWh/a]		
			Residential	**Other buildings**	**Trade and commerce**
MW	1.4	2,147	1,717	0	0
MW/U	1.0	1,007	1,941	0	0
MN	0.6	1,545	3,337	0	0
U-HA	4.9	0	0	2	3
KP/ZP/US	<0.1	0	0	0	0

MW- multifamily housing, **MW/U** - multifamily housing with commercial areas, **MN**- single family housing, **U-HA** - commercial areas (trade and administration), **KP/ZP/US/UO** - other buildings (*e.g.* educational)

Source: Author's

Energy demand of the case study area

The aim of the analysis was not to show how the current nZEB requirements can be fulfilled, but also to present options for possible future modifications of existing methodologies. According to the EPBD recast minimum requirements for electricity calculations are to include energy used for space heating, cooling, ventilation, hot water and lighting [7]. However, it is upon national decisions to take into account also electricity used by other appliances in households (occupants') electricity [11]. The delimitated area would be supplied with heating energy from the external municipal district heating (DH) system, in Warsaw so far 76% of inhabitants have been connected to the DH network [12]. Due to the above, on the demand side only electricity was considered for energy calculations (so far household appliances were excluded from EP calculations by the Polish legislation).

The electricity demands were calculated with current specific electricity demand assumptions, provided by the City of Warsaw [12], [13]:

- residential buildings: 800 kWh/inhabitant per annum,
- offices, educational entities 200 kWh/m^2 per annum,
- trade and commerce 570 kWh/m^2 per annum.

The above values for households energy consumption (including lighting and appliances) can be compared with those in other European places- in Scandinavian countries: 3,700 - 4,200 kWh/dwelling per year, as well as in Central and Eastern Europe: 1,000- 1,300 kWh/dwelling per annum [8]. Assuming that the size of an average household in Poland consists of 3 inhabitants, the above values can be regarded as a reliable.

The calculated total annual electricity demand for the whole urban unit was roughly estimated at 7.0 thousand MWh. However, it has to be remembered that for the residential housing electricity demand per capita in Poland has been much lower that the EU average, therefore, in the analyzed lifetime of 20 years a gradual increase to 10.4 thousand MWh was the calculation outcome (Table 5).

Energy supply with PV generated electricity

Under this research a simplified method was applied to show how to achieve a PV-nZEB standard (as an nZEB sub-standard) for areas, which are connected to district heating networks (therefore, only electricity demand-supply analyses were performed). A PV-nZEB unit can be defined [1] as a building with a relatively low electricity demand covered by a photovoltaic system (PV).

Three PV technological groups can be considered for application, their technical parameters are presented in Table 7:

- Ist generation: mono-crystalline solar cells (sc-Si), polycrystalline solar cells (mc-Si), multi-junction Si-thin-film (mj-cells),
- IInd generation: thin film amorphous silicon (a-Si), cadmium telluride thin-film solar panels (Cd-Te), CIGS thin-film technology (Copper Indium Gallium Selenide),
- IIIrd generation: DSSC – Dye Sensitized Solar Cells, organic solar cells (OSCs).

Table 6. Chosen technological parameters of I-III PV technology generation [14]

	Ist generation			**IInd generation**				**IIIrd generation**	
Name	mj-cells	sc-Si	mc-Si	a-Si	µc-Si	CdTe	CIGS	DSSC	oSC
Efficiency	30-43%	14-22%	13-18%	6-9%	6-11%	9-11%	10-12%	12%	4-6.5%
*Wp/m^2	n.a.	130-190	120-155	50-75	50-110	90-125	70-145	n.a.	n.a.

**peak power to area installed ratio*

Source: Author's

For the analyzed urban unit only two market well established PV technologies were chosen for further calculations: traditional polycrystalline solar cells (mc-Si) and a thin film amorphous silicon (a-Si) technologies (Figure 2). Additional assumptions refer to the decline of PV efficiency in time assuming the rate of 0.5% annually. Later climatic and technical data were used to calculate energy generation in a 20 year perspective (Figure 3).

polycrystalline solar cells (mc-Si)

Source: Internet
http://www.blpower.com.pk/coming-soon/solar-panel/

thin film amorphous silicon (a-Si)

Source: Internet
http://img.archiexpo.com/images_ae/photo-g/62630-7425769.jpg

Fig. 2 PV technologies chosen for calculations
Source: Author's

The roof area dedicated to PV installations was assumed in 3 variants: 30% of the total roof area (33 thousand m^2), 55% (61 thousand m^2) and 70% (77 thousand m^2) respectively.

Table 7. Energy calculations for polycrystalline solar cells (mc-Si), roof inclination angle 30 degrees, facing south

Roof area: 33 thousand m^2		**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Solar radiation intensity	Wh/m^2 per month	37,241	42,707	78,310	103,888	146,709	156,343	157,000	139,619	90,143	55,348	25,960	21,192
I_S_30	kWh/m^2 per annum	1.0 thousand											
Incident radiation	W/m^2	144	134	116	187	213	293	311	347	368	274	210	107
Peak power capacity	kWp	4.5 thousand											
Produced electricity	kWh per month	137,638	137,638	157,840	289,425	383,958	542,220	577,826	580,254	516,016	333,158	204,560	95,945
	MWh per annum	3.8 thousand											

Source: Author's

Results

Under this short research only annual electricity demand/supply balances were analyzed to exemplify the possibility to use buildings' roof for PV installations. It has to be remembered, however that electricity is only a part of the final energy consumption (apart from space heat, ventilation and hot water preparation). Thus, the proposed methodology can serve as an example of calculations in case of areas, which are supplied with heating by district heating networks.

This simplified case study showed that the available roof areas would allow to cover electricity demands for the Czerniaków urban unit only to a limited extent. The first limiting factor was that not the whole roof area can be designated for PV installations, the maximum was assumed at the level of 70%, as the remaining would need to be reserved for other technical functions of the building. In the initial analyzed period of the project 20 year life span, and the most efficient technological option of polycrystalline modules covering 70% of the roof area; the urban unit could produce more energy that it consumed (above 100% autarky level). However, in the later period (after 10 years) two unfavorable factors reverse the positive trend: a decrease of PV efficiency in time and the increasing electricity use per capita (including household appliances) would lower the level of energy to 80% (Figure 3). The choice of a PV technology also matters, the choice of less efficient amorphous silicon membranes resulted in much lower renewable energy shares compared with the polycrystalline PV solution. This is due to much lower peak power to area installed ratio (Table 7).

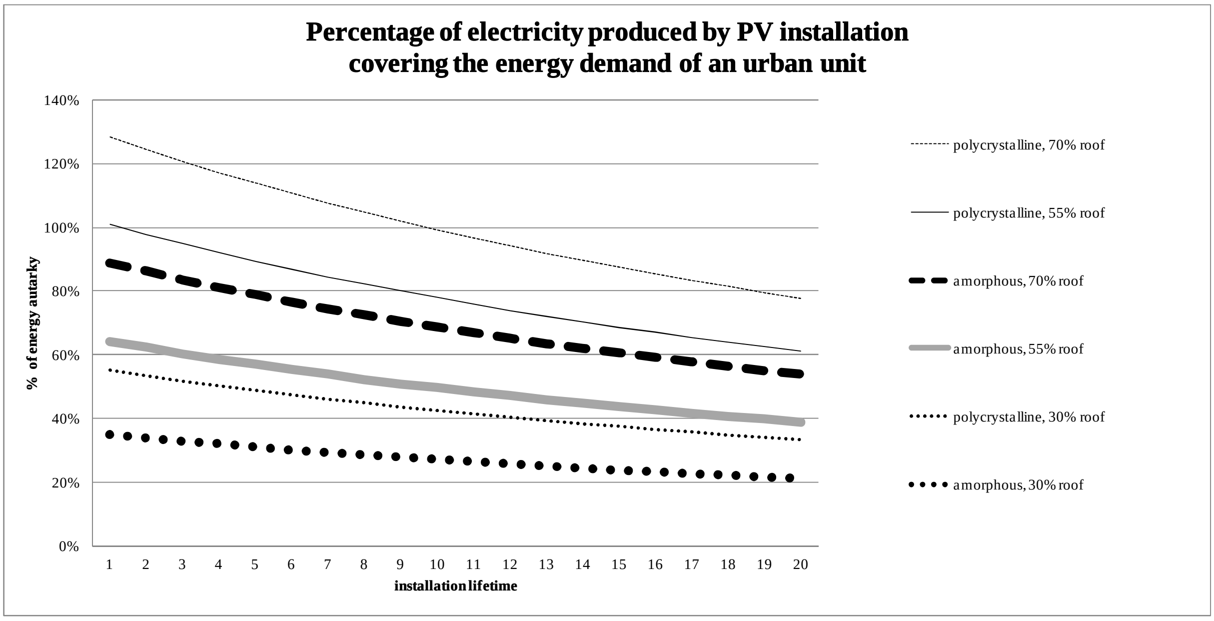

Fig. 4 Calculations of electricity autarky with the usage of 2 PV technologies taking up 30%, 55% and 70% of the available roof area of the urban unit.
Source: Author's

The indication for future modification of the nZEB methodologies would be that high shares of onsite renewables in the electricity balance of an urban zone would be difficult to achieve. An option could be to investigate the possibility of including in the calculation method wall mounted BIPV (building integrated) panels or nearby located generation sources - ground mounted, open space PV installations.

The simplification of the existing energy audit methodologies (departure from the energy audit detailed approach) served its usability and possibility of application at the urban zone level. This refers in particular to urban units, where only electricity balances are to be considered due to connection to an external, district heating system covering heating demands. The suggested new approach can contribute to its popularity among urban planners and other building/construction professionals.

Acknowledgements

This work was supported by the research leading to these results has received funding from the Polish-Norwegian Research Programme, KODnZEB project. http://kodnzeb.pl/

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IS THERE ANY CHANCE FOR UKRAINIAN RESEARCHES IN NANOSCIENCE?

Abstract

The article is devoted to revealing the peculiarities of Ukrainian researches in nanoscience and nanotechnology. The comparative analysis of publications, patents and R&D resources in Ukraine and developed countries has been performed. It is shown that the tendency in Ukrainian researches in nanoscience and nanotechnology corresponds to the global trend. But the share of researches in nanomedicine in Ukraine is significantly larger than that of the global ones, while the share of nanoelectronics is too small. The built models allow forecasting the number and share of publications in different branches and demonstrating the gap between Ukraine and other countries.

Key words

nanoscience, publication, patents, trends, forecast

Introduction

Nowadays nanotechnologies are becoming one of the major fields of science and technology in the world, a kind of mainstream for social progress in general. Developed countries are investing huge funds into scientific researches in the sphere. The transition to nanotechnologies, which means a creation of any material with a predetermined atomic structure, provides the most important result — dematerialization of production and a dramatic reduction of power and specific resource consumption. Nanotechnologies are already affecting and can fundamentally change electricity, energy, medicine and many other sectors of economies in the world. There is a problem of assessing the impact of nanotechnology on the development of different economic sectors, as well as mechanisms for state support of this direction in innovative economic development around the world. A few studies concerning the development of nanotechnologies in Ukraine have been done in the recent years [1], [2]. However, they cover a short time period and don't use such an important technique for receiving an objective assessment of Ukrainian and global tendencies as comparative analysis.

Ukraine, on the one hand, has an extensive network of research organizations, fundamental studies on relevant areas of researches, personnel with a high level of qualification, as it is justified by the demand for it in global weight factor. On the other hand, the research results in most cases do not reach the stage of commercialization. Research organizations do not have the financial capacity to build prototypes and ensure protection of the intellectual property rights, and business is not interested in implementation of innovative projects. A similar situation is observed in researches in the field of nanotechnologies.

The main aim of the study is to reveal the common features and peculiarities of R&D in Ukraine and to determine the perspective ways of developing nanotechnologies in Ukraine.

For the purpose we studied the publications of researchers in some developed countries and in Ukraine for the period of 1996—2014 in the field of nanoscience and nanotechnologies in general and in some individual spheres, such as:

- nanomaterials;
- nanoelectronics;
- nanomedicine;
- nanobiotechnology;

- nanotechnology in the energy sector;
- nanotribology.

Then we studied the dynamics of patent publications in nanotechnologies in different countries to determine the possibility for commercialization of nanotechnologies.

Materials and methods

Official statistical data of state institutions and international organizations, publications of a reference character, analytical monographs, annual statistical bulletins, Ukrainian State Statistical Bureau reports serve as an information basis for our research. Abstract database resources “Science Direct”, “SCImago Journal & Country Rank”, “Ukrainika Naukova” (Ukrainika Scientific), Scientific Electronic Library, Russian National Public Library for Science and Technology made up the information database of publication activities. The level of the R&D patenting in nanotechnologies was analysed by the data of Intellectual Property Organization, State Intellectual Property Service of Ukraine, a specialized database “Inventions (Utility Models) in Ukraine”. Models of time series, including trend analysis, were used for forecasting.

Analysis of publication activity

The review of publication activity in the field of nanoscience and nanotechnologies based on Science Direct database 0 proves that the USA, China, Japan, Germany and South Korea are the leading countries in the sphere. The total share of these countries in all publications for the period of 1996—2014 was 54.1 %. The EU countries’ share made up 28.1 %, while Ukraine had only 0.3 %. At the same time the indicators of 11 EU countries were even lower in comparison with Ukraine. China is on the top of the list during the past two years, while the USA started to lag behind in the recent 3 years.

Table 1 shows the dynamics in the number of publications in the countries. It demonstrates that globally and in separate countries the number of publications did not decrease except for Japan, where the number of publications was lower than in 2012. It proves the existence of constant interest to R&D work and inventions in this sphere.

Table 1. The number of publications in the subject category “Nanoscience and nanotechnologies” globally and in the leading world countries

Country	Years																		
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
WORLD	3299	3575	4259	3959	4527	5549	5465	6720	8173	9569	11331	15533	18487	19839	22589	26495	27685	29439	32042
China[1]	132	184	164	213	288	340	358	654	717	1074	1740	2425	3355	3713	4575	5450	6333	7977	9317
USA	1018	866	1254	1147	1274	1396	1522	1893	2289	2834	3239	4202	4936	5245	6173	6647	6875	7024	7393
Germany	413	468	511	446	544	652	723	644	856	810	970	1317	1454	1466	1711	1861	1918	1940	2096
South Korea	77	123	188	159	178	270	251	455	467	606	702	1021	1325	1330	1598	2461	2436	2741	2918
Japan	446	470	499	486	617	838	669	903	1021	1073	1216	1418	1476	1671	1633	1774	1826	1741	1781
Russia	75	158	264	135	259	391	106	199	217	151	190	341	467	508	577	571	712	627	698
Poland	37	58	34	40	64	65	57	68	131	82	112	158	184	155	168	191	247	255	262
Ukraine	13	40	52	49	42	49	38	47	51	61	56	55	88	57	76	72	110	106	133

[1] – except for Hong Kong. It also concerns the following tables.

Source: 0

The results shown in Table 2 prove that researches in nanoscience are attracting more attention. As we can see the share of publications in nanoscience in total publications increased in all countries. China demonstrates the largest annual growth rate of the share (near 12 %), Korea’s rate is 10.5 % and Ukraine’s rate is 6.9 %, while Poland has the lowest rate of 1.4 %. Judging from the largest share of publications, the researches in Korea are mostly concentrated at nanotechnology. So, we can assume that Korea has the highest effectiveness of researches in the sphere of nanoscience and nanotechnology. The smallest share is observed in Poland at the end of the period and it did not vary much. Ukrainian scientists are more "mobile" in the scientific area than Polish researchers and they can react to the global trends more quickly.

Table 2. The share of publications in the category "Nanoscience and nanotechnologies" in the total number of publications (in percentage terms)

Country	**Years**										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
China	0.66	0.67	0.92	1.13	1.33	1.24	1.36	1.41	1.57	1.82	2.06
United States	0.53	0.59	0.64	0,84	0.96	0.96	1.07	1.12	1.12	1.16	1.34
Germany	0.82	0.68	0.78	1.03	1.10	1.05	1.17	1.22	1.21	1.23	1.40
South Korea	1.49	1.64	1.64	2.18	2.62	2.47	2.66	3.74	3.47	3.77	4.04
Japan	0.95	0.89	0.99	1.20	1.25	1.35	1.31	1.39	1.42	1.36	1.55
Russia	0.60	0.39	0.54	0.96	1.27	1.33	1.46	1.33	1.62	1.35	1.38
Poland	0.63	0.35	0.44	0.62	0.66	0.54	0.56	0.60	0.71	0.70	0.73
Ukraine	0.73	0.83	0.84	0.81	1.23	0.81	1.01	0.87	1.20	1.11	1.44

Source: Author's

Basing on the dynamics of publications presented in Table 1, we tried to forecast the publication activities in the world with the help of time series models. Exponential, logarithmic, logistic, linear and quadratic models were tested. The best models built for each country and the global trend are presented in Table 3. Only China, Germany and Poland have an exponential growth in the number of publications, but China's growth rate is twice larger than that of the others. The growth rates of publications in the USA, Japan, Korea and Russia are logistic ones tending to the limits. That is why the growth of the global publication activity in the sphere of nanotechnology is logistic, too. Ukraine's trend corresponds to the quadratic function, which is worse than the exponential but better than the logistic one. This fact brings some hope for developing researches in the sphere.

Table 3. The models for forecasting publication activities in the world countries in the category "Nanoscience and nanotechnologies"

Country	**Model, R^2**
World countries	$Y_{world}(t) = \frac{1572.09}{0.033213 + e^{-0.21857t}}$, $R^2 = 0.99$, mape=6.9 %
China	$Y_{China}(t) = 183.993\ e^{0.20871t}$, $R^2 = 0.98$, mape=23.9 %
USA	$Y_{USA}(t) = \frac{409.864}{0.043228 + e^{-0.23982t}}$, $R^2 = 0.986$, mape=8.5 %
Germany	$Y_{Germany}(t) = 373.171\ e^{0.095t}$, $R^2 = 0.97$, mape=6.5 %
Japan	$Y_{Japan}(t) = \frac{332.838}{0.15707 + e^{-0.20116t}}$, $R^2 = 0.97$, mape=5.1 %
South Korea	$Y_{Korea}(t) = \frac{49.184}{0.010532 + e^{-0.27132t}}$, $R^2 = 0.99$, mape=8.6 %
Russia	$Y_{Russia}(t) = \frac{14.8761}{0.017837 + e^{-0.30757t}}$, $R^2 = 0.87$, mape=24.8 %
Poland	$Y_{Poland}(t) = 31.876\ e^{0.1159t}$, $R^2 = 0.92$, mape=11.5 %
Ukraine	$Y_{Ukraine}(t) = 0.2881t^2 - 1.3331t + 38.767$, $R^2 = 0.82$, mape=12.3 %

t = 1 corresponds to 1996

Source: Author's

Table 4 shows the forecasting results by the built models for emergence of new publications within the next three years globally and in separate countries. The largest share of scientific publications is observed in China, it makes up more than half of the total amount. The growth in number of publications in Russia, Poland, Ukraine and even Japan is slow. It should be noticed that the analysis was based on the data from Science

Direct 0, so publications in national journals not indexed in the SJR were not taken into account. It is a significant limitation for Ukraine because there are only a few indexed national journals. Despite of this fact, the total number of Ukrainian publications in 2015-2017 will be by 18 % larger than that in the recent three years, while the total number of Polish publications will grow by 1.4 times.

Table 4. Forecast of publishing activities in the world countries in the subject category "Nanoscience and nanotechnologies"

Country	**Years**		
	2015	**2016**	**2017**
World countries	34 290	36 252	37 998
China	11 958	14 733	18 152
USA	7 960	8 242	8 479
Germany	2 489	2 737	3 009
South Korea	3 294	3 542	3 758
Japan	1 917	1 954	1 985
Russia	745	767	783
Poland	324	363	408
Ukraine	127	138	149

Source: Author's

One of the most urgent and biggest problems of Ukrainian science are poor financial resources. That is why we tried to understand the dependency. The relationship between the R&D expenditure [4], [5] and the number of scientific publications in the chosen countries is presented in Figure 1. As one can see there is a controversial dependence. The USA, Germany, Korea and Japan have a higher level of expenditure but the number of publications per 1000 researchers is higher only in the USA and Germany. Moreover, the indicators of publication activity differ significantly among the three leading countries despite the same expenditure level. On the other hand, Poland demonstrates rising in the number of publications, while the level of R&D expenditure is increasing very slowly. A special case is China. Because of the extremely large population and the largest number of researchers but the smallest share of researches, China demonstrates average relative results at the largest absolute ones. So the level of R&D expenditure does not completely determine the publication activity of researchers, but the extremely low level of expenditure (as in Ukraine and Russia) leads to extremely poor results.

We studied the publication activity in the main sphere of nanotechnologies R&D according to the purpose. The distribution was studied basing on the DB Science Direct 0, "Ukrainika Naukova" [1], Russian Electronic Library [7], [8]. It is worth mentioning, that the data for 2014 as well as partially the data for 2013 could not be considered the final ones, as there is a big lag between the publication and its entering the abstract DB.

The general results show that the largest share of scientific publications is devoted to nanomaterials both globally (47.3 %) and in Ukraine (51.5 %) and Russia (33.7 %). Application of nanotechnologies in medicine against the rest of nano-areas has not gained the leading importance globally and in Russia yet. The same is true concerning nanotribology. A specific feature of Ukrainian nano-research is a comparatively high share of R&D in the spheres of nanobiotechnologies and nanomedicine. It brings a hope to develop new methods in solving health care problems, providing food products safety and improving agricultural production in Ukraine. With regard to the problem of global population ageing and national provision for safe food products, these spheres are promising for commercialization both globally and in Ukraine. But the nanoelectronics' share is very low, and this fact is a matter of concern as the high technology industry based on nanoelectronics is losing scientific support in Ukraine.

To assess the future situation we have built the models of trends in the number of scientific publications both globally and in Ukraine and Russia. They are presented in Table 5. The best models were obtained for the global trends. All of them are exponential ones with quite a high growth rate. The rate of nanotechnology in the energy sector is the greatest and that of nanomaterials is the lowest. The best model was built for number

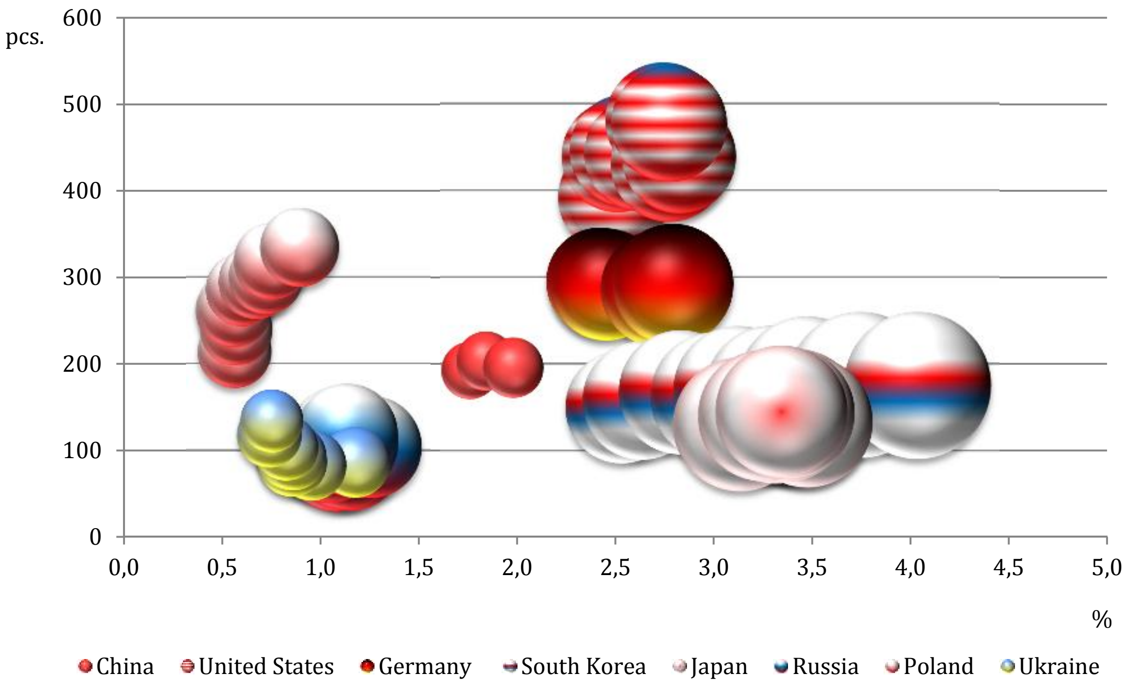

Fig. 1. The number of publications per 1000 researchers vs. total intramural R&D expenditure as a percentage of Gross Domestic Product. The size of the bubble reflects the number of researchers in R&D (per million people)
Source: Author's

of publications in nanobiotechnologies and nanomedicine In Ukraine. The number of publications concerning nanomaterials varies strongly, there is no model for this sphere as well as for nanotribology and nanotechnology in the energy sector in Russia. The model for Ukrainian publications in nanotribology is doubtful because of the small coefficient of determination. Low accuracy of the predicted values for the Ukraine and Russia (mape) is explained by volatile dynamics and small numbers, especially in Ukraine. However the forecast allows us to see the general trend. The common feature in the models for Ukrainian nano-research is a low growth rate. The models for the four spheres of nanotechnologies R&D in Russia are logarithmic ones, so the growth in these spheres slows down.

Table 5. Models for forecasting trends in the number of publications by the spheres of nanotechnologies R&D.

Sphere of nanotechno-logies R&D	**Models for forecasting the number of scientific publications**		
	Globally	**In Ukraine**	**In Russia**
Nanomaterials	$y=2353.74*e^{0.105871t}$, $R^2=0.98$, mape=3.7 %	Random (100; 160)	$y = -473.77+223.94*LN(t)$, $R^2=0.88$, mape=17.0 %
Nanoelectronics	$y=1034.78*e^{0.130405t}$, $R^2=0.99$, mape=2.8 %	$y = 2.1947*e^{0.142571*t}$, $R^2=0.74$, mape=22. 1%	$y = -297.107+151.18*LN(t)$ $R^2=0.72$, mape=27.4 %
Nanobiotechno-logies	$y=303.361*e^{0.163925*t}$, $R^2=0.98$, mape=10.4 %	$Y(t) = \frac{0.25759}{0.001448 + e^{-0.385t}}$, $R^2=0.95$, mape=23.2 %	$y = -308.162+141.857*LN(t)$, $R^2=0.88$, mape=27.8 %
Nanomedicine	$y=21.7361*e^{0.155316*t}$, $R^2=0.96$, mape=11.4 %	$y = -49.8+5.733*t$, $R^2=0.95$, mape=24.4 %	$y = -62.545+6.6182*t$, $R^2=0.85$, mape=36.1 % (exclude 2004, 2006)
Nanotechnology in the energy sector	$y=99.1287*e^{0.181985*t}$, $R^2=0.97$, mape=9.5 %	$y = -6.459+0.8243*t$, $R^2=0.71$, mape=37.0 % (exclude 2011, 2014)	Random (15;60)
Nanotribology	$y=17.5268*e^{0.117786*t}$, $R^2=0.88$, mape=10.5 %	$y = 1.567*e^{0.109*t}$, $R^2=0.58$, mape=21.0 %	Random (2;10)

Source: Author's

With the help of building the models we forecasted the number of new publications in the spheres. During the next three years the total number of the publications in all the studied areas would exceed the volumes of the publications in the recent three years by 1.5 times. And R&D in nanobiotechnologies, nanomedicine and nanotechnology in the energy sector have the largest share increase in the global process (Table 6), while the share of nanomaterials decreases. In Ukraine there observed the same tends for all the spheres except for nanoelectronics. And during the next three years the nanobiotechnology's share will be the largest. However, the growth rates of the total number of publications and those in the four spheres are lower than in whole in the world. The deviations from the global weight factors for R&D in Russia are not significant except for nanomaterials but the growth rate is larger. So the distribution of R&D in Russia among the spheres corresponds to the global trends.

Table 6. Forecast of new publications emergence by the spheres of nanotechnologies R&D

Years	**Spheres of nanotechnologies**						
	Nano-materials	**Nano-electronics**	**Nano-biotechnologies**	**Nano-medicine**	**Nanotechnology in the energy sector**	**Nano-tribology**	**Total publica-tions**
Globally							
2015	19 559	14 045	8 050	486	3 775	185	46 099
2016	21 743	16 002	9 484	567	4 528	208	52 532
2017	24 171	18 231	11 173	662	5 432	234	59 904
Forecasted weight factor for the sphere	41.3	30.5	18.1	1.1	8.7	0.4	
Ukraine							
2015	112	38	136	65	10	14	374
2016	113	44	147	71	11	15	400
2017	148	51	155	76	12	17	459
Forecasted weight factor for the sphere	30.2	10.7	35.5	17.2	2.6	3.8	
Deviation from the global weight factor	-11.1	-19.8	17.4	16.1	-6.1	3.4	
Deviation from the global growth rate	-0.09	0.03	-0.01	0.03	-0.14	-0.01	-0.06
Russia							
2015	197	156	117	70	48	9	597
2016	208	163	124	76	32	5	608
2017	218	170	130	83	32	7	641
Forecasted weight factor for the sphere	33.8	26.5	20.1	12.4	6.1	1.1	
Deviation from the global weight factor	-11.3	-1.3	3.7	9.4	-1.2	0.6	
Deviation from the global growth rate	0.14	0.06	0.08	0.17	0.21	-0.09	0.11

Source: Author's

Our analysis shows some perspectives for Ukrainian researches in nanoscience and nanotechnology. The biggest advantage is to focus the attention of business on researches in the sphere of nanomedicine and nanobiotechnology, while the state grants should support fundamental and applied researches in nanoelectronics and nanotechnology in the energy sector.

Analysis of patents publication

The next step was the assessment of patent activity in nanotechnologies. Only a few countries including China, the USA, South Korea, Japan and Germany are the undoubted leaders in terms of this indicator in recent years.

They have 80 % of the total number of published applications in the sphere of micro-structural and nanotechnology 0. The annual number of published patents in Ukraine is extremely small in comparison with that in Poland (Table 7).

Table 7. Total number of patent publications in the sphere of micro-structural and nanotechnology by the applicant's origin

Country	**Years**										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
China	47	105	154	200	269	301	540	698	1207	1260	1510
USA	654	549	477	496	543	549	530	530	677	655	695
Germany	216	223	223	240	243	323	301	301	311	307	373
South Korea	203	233	308	440	416	610	761	619	452	454	387
Japan	575	676	620	679	612	617	482	475	459	446	473
Russia	8	7	10	28	69	139	202	220	213	251	201
Poland	1	2	2	2	7	8	4	12	14	23	21
Ukraine	2	1	1	1	4	1	1	3	5	18	8

Source: [9], [0], [11]

The consideration of relative indicators of patent activity shows at first sight positive features for Ukraine concerning the patents in the sphere of nanotechnology (Table 8). Unfortunately, the comparison is made against the overall low patent activity across all technologies.

Table 8. The share of patent publications in the sphere of micro-structural and nanotechnology in the total number of patent publications by the applicant's origin (in percentage terms)

Country	**Years**										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
China	0.10	0.14	0.16	0.17	0.17	0.16	0.23	0.25	0.28	0.24	0.23
United States of America	0.17	0.14	0.12	0.13	0.13	0.14	0.14	0.14	0.17	0.15	0.15
Germany	0.13	0.13	0.13	0.14	0.14	0.18	0.17	0.17	0.17	0.17	0.21
South Korea	0.18	0.16	0.18	0.25	0.27	0.39	0.47	0.37	0.26	0.24	0.21
Japan	0.11	0.13	0.12	0.14	0.13	0.13	0.10	0.11	0.10	0.09	0.11
Russia	0.03	0.02	0.04	0.11	0.22	0.43	0.70	0.75	0.70	0.81	0.77
Poland	0.04	0.07	0.08	0.08	0.27	0.29	0.12	0.34	0.30	0.40	0.34
Ukraine	0.02	0.04	0.06	0.04	0.13	0.04	0.04	0.13	0.23	0.74	0.67

Source: Author's

The results of studying the relation between patent publications and R&D expenditure are quite different from the previous comparison. As we can see in Figure 2, there is almost linear dependence except for the unstable case of Korea. The lowest level of financial support to R&D in Ukraine and Poland results in the poor patent publication activity. The largest number of patents is demonstrated by Japan and Korea. This fact allows concluding that these countries conduct more applied researches and there are more close links between science (universities, research centres) and business (enterprises, TNCs). Financial capability is crucial for making such a background for commercialisation as a sufficient number of patents.

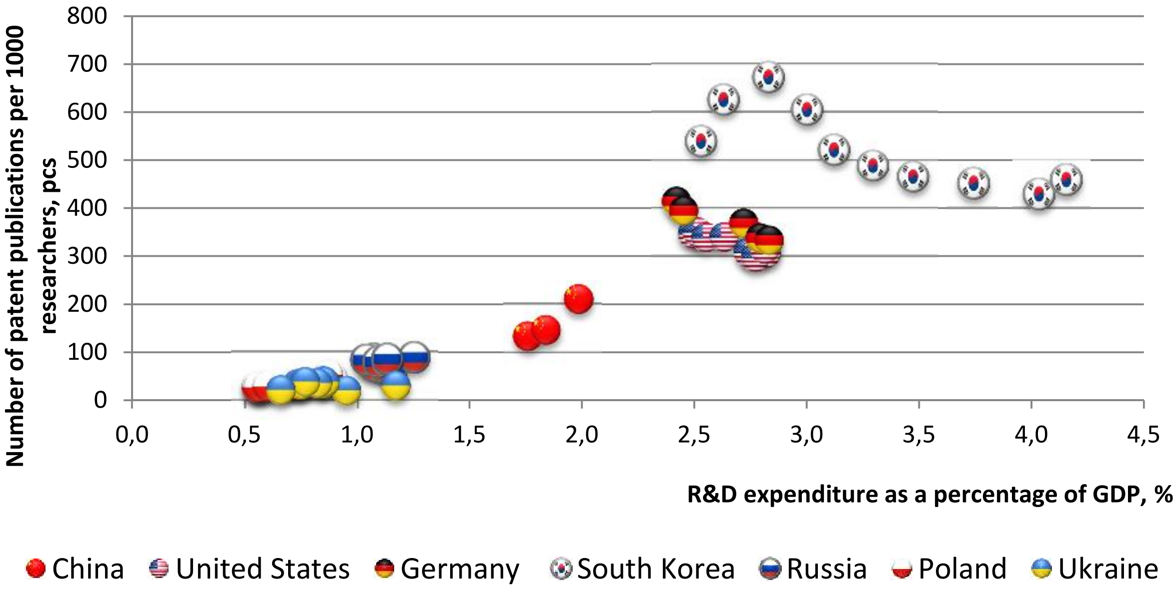

Fig. 2. The number of patent publications per 1000 researchers vs. total intramural R&D expenditure as a percentage of Gross Domestic Product.
Source: Author's

The most of patent applications are submitted to SIBSU under the national procedure. To determine the patent activity in the sphere of nanotechnologies, the data retrieval was performed by IPC index B82 "Nanotechnologies" for all the years available in DB 0 except for 2015. The retrieval results showed that the number of patents sharply increased in 2008. However, the total number of the valid patents in the sphere "Nanotechnologies" nowadays is only 87. Many patents have a wide field of application, they relate mainly to technologies of creating nanomaterials, nanoliquids and nanocovering and can be used in various industrial processes. The largest part of the patents concerns medicine (25) and the number of patents in nanobiotechnology is comparatively large too (17 for agriculture and 13 for food production). This allows concluding that researches in these spheres are more applicable and could present some kind of commercial prospect.

Summary and conclusions

Lisbon Strategy encourages EU countries to increase the volume of investments on research and development (R&D) 0. There is a goal to achieve the R&D expenditure ratio amounting to 3% of GDP. This is a challenge even for countries with a high level of economic development, but almost all EU and developed countries were increasing their expenditure in previous years.

The R&D support in Ukraine is extremely poor, so this area is under the poverty line and neither theoretical nor experimental, nor effective applied researches are possible. To reach the level of developed countries and an appropriate level of competitiveness among European countries, Ukraine should expand the state financial support to scientific and technological development.

The peculiarity of the Ukrainian research field is a high proportion of developments in nanomedicine and nanobiotechnology both in scientific publications and patent applications. That's why these spheres should be considered as the most competitive advantages of the nanotechnology development in Ukraine and should gain a state support in commercialization. To maintain the existing potential, Ukraine has to provide the state support to local development, especially at the stage of fundamental research, and institutional support to the interaction of science and business at the stage of applied research.

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