

The Book of Articles National Scientific Conference "Science and Young Researchers" III edition

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Promovendi Foundation Publishing

Adress: 17/19/28 Kamińskiego st. 90-229 Lodz, Poland

KRS: 0000628361 NIP: 7252139787 REGON: 364954217

e-mail: fundacja@promovendi.pl www.promovendi.pl

ISBN: 978-83-952839-7-0

The papers included in this Book of Articles have been printed in accordance with the submitted texts after they have been accepted by the reviewers. The authors of individual papers are responsible for the lawful use of the materials used.

Circulation: 50 copies

Łódź, June 2019



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HERBAL EXTRACTS IN NOSEMOSIS TREATMENT IN HONEYBEE (APIS MELLIFERA L.)

Ewelina Berbeć^{1*}, Paweł Migdał²

¹ Studenckie Koło Naukowe Pszczelarzy "Apis", Department of Environment, Animal Hygiene and Welfare, Wroclaw University of Environmental and Life Sciences

² Department of Environment, Animal Hygiene and Welfare, Wroclaw University of Environmental and Life Sciences * corresponding author: ewelanina.nina@gmail.com

Abstract:

Nosemosis is a microsporidian honeybee (*Apis mellifera* L.) disease, highly common nowadays. For the reason of lack of any both effective and safe drug in the treatment of this disease, it is still searched. Herbal extracts which include natural compounds and have not a negative influence on human health could potentially solve this problem. In recent years some plant extracts in nosemosis treatment was studied, and several of them had a positive effect on bees and negative on nosemosis. It obligated authors to gather knowledge of the influence of herbal extracts on bees, especially *Nosema* spp. spore load per bee after inoculation and bees mortality, which are main factors showing if tested substance qualify to be used in *Nosema* disease treatment.

Keywords:

nosemosis, honeybee, Apis mellifera, herbal extracts

Introduction

Nosema disease

Nosemosis is one of the most widespread honeybee (*Apis mellifera* L.) disease. It is caused by two species of microsporidians: *Nosema apis* Zander and *Nosema ceranae* Fries. *Nosema apis* infection is typically seasonal, with intensive rise in ending of winter and in spring, and often dues to spring falls. Smaller rise occur in fall. Rise of *Nosema ceranae* infection is not so sesonal and can occur at any time of the year. Yet in XX century western honeybee *Apis mellifera* L. hosted only one of them: *Nosema apis*. Originally *Nosema ceranae* used to occur in the Asian honeybee *Apis cerana* Fab., but at the beginning of the XXI century it was detected in western honeybee *Apis mellifera* L. This pathogen spread very fast to apiaries all over the world, and now is detected in all continents where honeybee occurs, even in Australia, which is the only continent still free of warrosis (another widespread honeybee disease, also spread at the last decades from Asian honeybee *Apis cerana* Fab.). There are some differenties between *Nosema apis* and *Nosema ceranae* infections. Intensive *Nosema apis* infection, except for generally weakeness of bees and whole bee colony, spring falls, increased mortality and decline in honey and brood production, appears in diarhorrea. On the other hand, *Nosema ceranae* infection does not appear by so visible



symptoms, and for this reason is more difficult to notice. Treatment the *Nosema* disease is difficult. The only drug was antibiotic fumagilin produced by fungus *Aspergillus fumigatus* Fresenius. But this substance is toxic for mammals including human, and was verified that in threated bee colonies spreads to honey, so European Union refused using it [1]. What is more, there are reports that *Nosema* could escape control of this antibiotic [2]. That leads reaserchers to examine other substances to be useful in nosemosis treatment in honeybee.

Herbal extracts

Herbs are used in traditional medicine in treatment plenty of human and animal diseases. Plants owe their activity to natural biological active compounds, which may have positive influence against desease and cause fewer side effects than chemical synthetised substances [3]. There are different kinds of extracts, differ by the solvent and fraction. Aquatic extracts include polar, water soluble, hydrophilic substances. Alcohol extracts, most often used ethanolic extracts, include polar and non-polar compounds. Organic solvents, such as buthanol, extract non-polar, hydrophobic substances. Essential oils include volatile fraction. Each of them includes different compounds and often displays diverse properties. What is more, even different parts of the same plant may contain dissimilar components. Effect also strongly depends on dose. For this reason no only information about the species of evaluated plant is important, but also type of extract, method of extraction, part of plant and used in research concentration of active substance [4].

Studied plants extracts which have given positive effect against nosemosis

Artemisia absinthium L. (Asteraceae)

Artemisia absynthium is one of herbs used in human medicine. It contains many biologically active compounds: absinthinum, essential oils, flavonoids, organic acids, tannins and mineral salts [5]. Artemisia absinthium essential oil was shown to have antifingal activity and inhibitory effect against some of bacterial strains [6]. Ethanol extract of this plant showed trematocidal effect [7]. Pohorecka tested the 5 and 10% Artemisia absinthium ethanol extracts influence on Nosema apis natural and artifical infection in honeybee. All threated groups showed higher mortality rate of beescompared to control. Extracts in both concentrations significantly inhibited Nosema apis development in naturally and artifically infected bees. Higher extract concentration demonstrated stronger influence, but also higher bees mortality [5]. Porrini et al. [8] studied 1 and 10% Artemisia absinthium ethanol extract in concentration 1% caused median survival similar to control, but in concentration 10% showed toxic effect, significantly rising bees mortality. For this reason effect on Nosema ceranae infection was tested only for extract in concentration 1%. The spore load was not decreased throughout this experiment.

Laurus nobilis L. (Lauraceae) - laurel leaf

Dried leaf of *Laurus nobilis* is a well-known, widely used in culinary and food industries seasoning [9]. Laurel leaf extract has a antimicrobial and antifungal activity [10-12], and also antioxidant properties [13]. It was proved that laurel leaf ethanol extract has higher antifungal activity against *Aspergillus niger* Tiegh. and *Candida albicans* (C.P. Robin) Berkhout than nystatin



[10]. In traditional medicine is used in prevention and treatment in many human and animal illnesses. In a research of Damiani et al. [9] *Larus nobilis* ethanol extract, essential oil, hydrolate, and 1,8-cineol (main compound of essential oil and hydrolate) and their effect on *Nosema ceranae* development and bee mortality was examined. High concentration of ethanol extract (1 x $10^5 \mu g/ml$) at day 7. post inoculation caused significant decrease in spore load (6,60 x 10^4 vs. 2,20 x 10^6 spores per bee on average compared to control group), but high bee mortality. Given in smaller concentration (1 x $10^4 \mu g/ml$) at day 19. post inoculation caused decrease in spore load in threated group (3,02 x 10^6 vs. 7,16 x 10^6 spores per bee on average compared to control group) without increasing bees mortality. Essential oil, hydrolate and 1,8-cineol used long-term showed neither significant effects against *Nosema ceranae* development nor bees mortality, except hydrolate which in concentration 3 x 10^5 caused higher bees mortality. Ethanol extract had also the best antimicrobial activity agaist *Paenibacillus larvae* and significant antiparasitic activity on *Varroa destructor*. Porrini et al. [8] showed that 1% laurel leaf ethanol extract significantly inhibit *Nosema ceranae* infection 19 days after inoculation. Extract in concentration 10% is effective in a shorter period of time, but causing high bees mortality.

Artemisia dubia Wall. (Asteraceae) and Aster scaber Thunb. (Asteraceae) - East Asian herbs

These plants was the two of chosen to test they possibility to be used in nosemosis treatment by their abundance and easy accessibility in research of Kim et al. [14]. It was shown that ethanol extract of each of them is not killing for IPL cells (directly IPL-LD-65Y cell line, from Lymantria dispar larvae [15]) demonstrate antinosemosis activity in in vitro (on IPL cells infected Nosema ceranae spores) and in vivo study (in cage experiment with Nosema ceranae infected bees). Feeding uninfected bees 60% sucrose solution of Artemisia dubia and Aster scaber ethanol extract had no influence on mortality rate until concentration 25 µg/ml. Higher concentrations (50 µg/ml and 100 µg/ml) of each of them caused increased uninfected bee mortality. Nosema ceranae infected bees fed with Artemisia dubia or Aster scaber 25 µg/ml etanol extract demonstrated higher survival rate and decrease in spore load (Aster scabeer extract caused slightly less survival rate and higher spore load than Artemisia dubia extract). Mix of these two extracts was also tested, and it demonstrated better results that single plants extracts. In concentration 100 µg/ml caused until 77% Nosema spores reduction without *in vivo* toxicity. Lee et al. [4] tested other kinds of extracts: aqueous, ethyl acetate, and butanol extracts of Aster scaber, Artemisia dubia and both plants. Aqueos extract of mixed Artemisia dubia and Aster scaber, in which butanol and ethyl acetate soluble compounds were eliminated, reduced the number of spores to almost 76% at 1 µg/ml concentration, so it works widely more effective than ethanol extract. Other types of extracts also demonstrated antinosemosis activity, but not as strong as aqueotus extract. These results shows that Aster scaber and Artemisia dubia have more than one anti-nosemosis compound with different solublity in each solvent, and synegristic effect between extracts from these plants is visible.

Cryptocarya alba (Mol.) Looser, (Lauraceae) - native Chilean tree

Cryptocarya alba leaves contain 0,3% essential oil, the main components of which are α -pinene, β -pinene, β -terpinene, cymol, 1-terpinen-4-ol, and eucalyptol. *Cryptocarya alba* leaves essential oil was reported to demonstrate antifungal activity [16]. Essential oil and powder of



Cryptocarya alba foliage showed insecticidal activity and repelent effect against *Sithophilus zeamays* Motschulsky (*Coleoptera*, corn grains pest): LC₅₀ for powder equals 50 g powder/kg grain and for essential oil 14,6 ml essential oil/kg grain [17]. Bravo et al. [18] studied potential of use the *Cryptocarya alba* essential oil in honeybee nosemosis treatment. Essential oil in concentrations 1, 2, 3 and 4 µg/bee (selected on low toxicity) and its main monoterpeny compounds: β -phelloandrene, eucalyptol and α -terpineol, every in concentration 20 µl/bee, were tested. None of them negatively influenced bees survival under laboratory conditions over 8 days of treatment. The best results in decreasing the number of spores in *Nosema ceranae* infected bees was shown for essential oil in concentration 240 µg/bee. Evaluated compounds also demonstrated significant effect against *Nosema ceranae* infection, but the effect use of essential oil was significantly higher.

Aristotelia chilensis (Mol.) Stuntz. (Elaeocarpaceae), Ugni molinae Turcz. (Myrtaceae) and Gevuina avellana Mol. (Proteaceae) - native Chilean herbs

These herbs were reported to have antimicrobial activity against human pathogens [19]. Arismendi et al. [19] tested metanol extracts of these plant leaves to evaluate possibility of using them against nosemosis in honeybee. Bees were fed with pollen substitute included plant extracts in concentrations 2, 4, 8 and 16%. When bees were first *Nosema ceranae* inoculated and then threated (curative threatment), methanol extracts of *Aristotelia chilensis* in 8% and *Ugni mollinae* in 2% and 8% concentrations significantly decreased spore load and improved survival rate of bees. The highest concentration (16%) of all extracts was toxic for bees, survival rate was around 30%. Extract of *Aristotelia chilensis* the most affected bees survival. *Ugni molline* extract appeared to be less toxic to the bees and increased mortality only in the highest concentration. On the other hand, when bees were first threated with extracts in concentrations 2% and 8%, then *Nosema ceranae* infected and after inoculation were still threated (preventive treatment), their diet consumption increased and all extracts decreased *Nosema* spore significantly.

Other plant extracts which demonstrated inhibitory effect against *Nosema* development in honeybee

- Decoctions of *Andrographis paniculata* (Burm. F.) Nees, *Phellodendron chinense* Schniedt. and ethanolic extracts of *Vitis vinifera* L. skin respectively displayed efficient potentials to control *Nosema ceranae* [20, 21]. Also combinations of these three herbal extracts was evaluated, but any of them showed stronger effect than the single ones [21].
- *Curcuma longa* L. extract demonstrated to be no toxic to bees at laest at 1%, and given in concentration 0,5% had significantly reduced *Nosema ceranae* spores production to 92,5% compared to control [22].
- Use of *Thymus vulgaris* L. ethanolic extracts in concentrations 0,50; 0,75; 1; 1,50 and 2 mg/ml also has given promising results by significant *Nosema apis* spores reduction [23].



Studied plants extracts which not demonstrated anti-nosemosis activity

The information about plant extract which demonstrated toxicity for bees or did not influence decreasing on nosemosis infection is highly valuable for further studies. The data summary is demonstrated in Tab. 1.

Plant species	Part of plant	Extract type and concentration	Effect	Source
Vetiveria zizanoides Nash.	leaves	EO 1,2 mg/g	No effect against N. ceranae	[24]
Ilex paraguensis A.StHil.	leaves and stems/trun ks	EtOH 1% and 10%	Toxic for bees	[8]
Allium sativum L.	garlic cloves	EtOH 1%	No effect against N. ceranae	[8]
Achyranthes japonica (Miq.) Nakai	leaves	EtOH 10%	Toxic for bees	[8]
Allium senescens L. Var. senescens	leaves	EtOH 12,5 µg/ml, 25µg/ml, 50 µg/ml, 100 µg/ml	Toxic for IPL cells	[14]
Amaranthus mangostanys L.	leaves	EtOH 12,5 μg/ml, 25μg/ml, 50 μg/ml, 100 μg/ml		
Astilboides tabularis (Hemsl.) Engl.	leaves	EtOH 12,5 μg/ml, 25μg/ml, 50 μg/ml, 100 μg/ml		
Lythrum salicaria L	leaves	EtOH 12,5 μg/ml, 25μg/ml, 50 μg/ml, 100 μg/ml		
Mentha arvensis L.	leaves	EtOH 12,5 μg/ml, 25μg/ml, 50 μg/ml, 100 μg/ml		
<i>Perilla frutescens</i> var. Acuta Kudo	leaves	EtOH 12,5 μg/ml, 25μg/ml, 50 μg/ml, 100 μg/ml		
<i>Physalis alkekeng</i> i var. francheti (Mast.) Hort	leaves	EtOH 12,5 μg/ml, 25μg/ml, 50 μg/ml, 100 μg/ml		
Rheum undulatum L.	leaves	EtOH 12,5 µg/ml, 25µg/ml, 50 µg/ml, 100 µg/ml		
Schisandra chinensis (Turcz.) Baill.	leaves	EtOH 12,5 μg/ml, 25μg/ml, 50 μg/ml, 100 μg/ml		
Symphytum officinale L.	leaves	EtOH 12,5 μg/ml, 25μg/ml, 50 μg/ml, 100 μg/ml		
Veratrum oxysepalum Turcz.	leaves	EtOH 12,5 μg/ml, 25μg/ml, 50 μg/ml, 100 μg/ml		
Achillea alpina (Ledeb)	leaves	EtOH 50 µg/ml, 100 µg/ml	No effect against N. ceranae	[14]

Tab. 1.	Summary of studied herbal extracts	s with no positive	effect on nosemosis
	EO - essential oil, EtOH	- ethanolic extra	ct

Source: own work based on source literature



Plant species	Part of plant	Extract type and concentration	Effect	Source
Aster tataricus L.f.	leaves	EtOH 50 µg/ml, 100 µg/ml	No effect against N. ceranae	[14]
Astragalus membranaceus Bunge var. membranaceus	leaves	EtOH 50 μg/ml, 100 μg/ml		
<i>Cirsium nipponicum</i> (Maxim.) Makino	leaves	EtOH 50 µg/ml, 100 µg/ml		
Disporum uniflorum Baker	leaves	EtOH 50 µg/ml, 100 µg/ml		
Cinnamomum zeylanicum Blume	leaves	EO 333 mg/kg	No effect against N. ceranae	[25]
		EO 666 mg/kg	Toxic for bees	[25]
Eucalyptus globulus Labill.	leaves	EO 333 mg/kg	Toxic for bees; no effect against <i>N. ceranae</i>	[25]
		EO 666 mg/kg	Toxic for bees	[25]
Laurus nobilis L.	leaves	EO 666 mg/kg	No effect against N. ceranae	[25]
Origanum vulgare L.	leaves	EO 666 mg/kg	No effect against N. ceranae	[25]
Rosmarinus officinalis L.	leaves	EO 666 mg/kg	No effect against N. ceranae	[25]

Source: own work based on source literature

Herbal natural components influence on nosemosis

Herbal extracts owe theirs activity to active components which they include. For this reason anty-nosemosis activity of the effective extracts main components are also evaluated. The data summary of evaluated substances are included in Tab. 2.



Component	Concentration	Effect	Source	
Thymol	0,12 g/kg	Lower N. ceranae spores level	[24]	
	100 ppmLonger bees survival time under cage experiment; lower N. ceranae spores level			
Resverathrol	0,001 g/kg	Longer bees survival time under cage experiment; lower <i>N. ceranae</i> spores level	[24]	
	10 ppm	Longer bees survival time under cage experiment	[26]	
Caffeine	5 μg/ml	Longer bees survival time under cage experiment; inhibiting effect against <i>N. ceranae</i> development	[27]	
Coenzyme Q10	0,2 mg/ml	Longer bees survival time under cage experiment; inhibiting effect against <i>N. ceranae</i> development	[28]	
1,8-Cineole	333 ppm, 3333 ppm, 6666 ppm	No effect against N. ceranae	[9]	
	6666 mg/kg	No effect against N. ceranae	[25]	
Curcumin	3 μg/ml	Longer bees survival time under cage experiment; inhibiting effect against <i>N. ceranae</i> development		
α-Phellandrene	333 mg/kg	No effect against N. ceranae	[25]	
Carvacrol	333 mg/kg	Toxic for <i>N. ceranae</i> infected bees – possibly combined effect; significant spores decrease	[25]	
	6666 mg/kg	Toxic for non-infected bees	[25]	
Cinnamaldehyde	6666 mg/kg	Toxic for bees; no effect against N. ceranae		
β-Myrcene	6666 mg/kg	No effect against N. ceranae		
Porphyrine:	10 µM	N. ceranae spores decrease	[30]	
PP(Asp)2	100 μΜ	Longer bees lifespan; <i>N. ceranae</i> spores decrease, stronger effect than dose of 10 μ M	[30]	
Porphyrine: TmePyP	100 μM	Number of <i>N. ceranae</i> spores reduction	[30]	

Tab. 2. Results summary of studied herbal extracts compounds effect on Nosema disease

Source: own work based on source literature

Commercial beekeeping products based on herbal extracts

Activity of natural substances occuring in herbal extracts have been appreciated by commercial producents of beekeeping feed supplements products:

Nozevit[®] and Nozevit $+^{\text{®}}$ - described as natural herbal product. Dedicated to bee colonies to limit nosemosis development and improve bee colony condition. Contains oak bark extract, which is known as rich source of tannin - polyphenolic substances; also includes vitamins, essentials oils and citric acid [31-33].

Protofil[®] - natural product obtains by hydro alcoholic extraction. Contains substances from different plants, vitamins and microelements. Used to its nosemosis development prevention effect and stimulant effect on bee colonies [34].



VitaFeed Gold[®] - is a water extract of *Beta vulgaris* L. cv *altissima* rich in sodium salicylate and molasses. Stimulates colony growth and brood population in a controlled manner; recommended also in nosemosis treatment [35].

ApiHerb[®] - based on plant extract, essential oils and B vitamins. Improves the condition of the bees affected by nosemosis [36].

HiveAlive[®] - is composed of selected Irish seaweed extracts. Improves bee health, nutrition, production, reduce disease levels (including nosemosis) [37, 38].

The informations about other tested plant extracts can be found in patents informations published in internet:

- Fennel oil [39];
- Pine needles extract and Sorbus aucuparia L. juice [40];
- Composition of extracts selected from: *Crocus sativus* L., *Pelargonium graveolens* L'Hér, *Monarda citriodora* Cerv. ex Lag., *Myristica fragrans* Houtt., *Origanum vulgare* L., *Origanum majorana* L., *Thymus vulgaris* L., *Aloe arborescens* Mill. *and Beta vulgaris* L. [41];
- Composition of extracts: horsetail (*Equisetum* spp. L.), eucalyptus, wormwood (*Artemisia absynthium* L.), bitter red pepper cayenne, *Echinacea purpurea* (L.) Moench, garlic (*Allium sativum* L.) and pine needles [42];
- Olea europaea L. [43];
- Grape skin [44, 45];
- Andrographis paniculata (Burm. F.) Nees [46];
- *Phellodendron* spp. Rupr. [47, 48];
- Polygonum cuspidatum Siebold & Zucc. [49];
- Quisqualis spp. L. and Szechwan Chinaberry Fruit (Fructus Toosendan) extract [50];
- *Cryptocaria alba* (Mol.) Looser [51];
- Eleutherococcus spp. Maxim. [52];
- Aster scaber Thunb., Artemisia lavandulaefolia Salisb. [53];
- Ocimum kilimandscharicum Gürke [54];
- Curcuma longa L. [55];
- Hemp essential oil [56].

Summary

Herbal extracts have a potential to be used in *Nosema* disease treatment in honeybee, altrough mechanism of working is still unknown. As was shown, sometimes composition of extracts gives better results than single one, and the whole extract influece better than single components. This phenomenon can be explained as synergic effect between compounds which plant extracts include. Maybe creation the composition of eductioned from herbal extracts single active substances with using synergic interactions between them could lead to elicitation the efficient drug. There are plenty of plant species on the Earth, and only really tiny part of them was studied in recpect to beekeeping usage and effect on insects physiology. But further studies are needed, our whole



knowledge is still infinitesimal compared to natural processes we can observe, and for the time being we can only search for suitable cure by testing single samples in order. But this searching by herbs used for centuries in human medicine has just given some positive results.

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COMPARATIVE STUDY ON TRIBOLOGICAL PROPERTIES OF A GREASE CONTAINING GRAPHENE OXIDE OR HEXAGONAL BORON NITRIDE

Igor Jakub Dąbrowski

Military University of Technology, Faculty of Mechanical Engineering, 00-908 Warsaw, ul. gen. Sylwestra Kaliskiego 2 corresponding author: dabrowski.igo@gmail.com

Abstract:

The purpose of this publication is to present the results of tests of the grease base with consistency class 2 according to the NLGI classification contained various concentrations of graphene oxide GO or hexagonal boron nitride h-BN. The first part of the paper presents basic information about graphene and its applications, especially in the field of tribology. The second part of the article presents the results of tests of tribological properties of samples contained 0.05%, 0.1%, 0.5%, 1% and 2% (w/w) of GO or h-BN. In addition, the tribological properties of the "Graphene paste", have also investigated. The measurements were carried out using the T-02 four-ball apparatus and the UNMT universal nanomicro tribotester. The results obtained have shown the beneficial effect of adding additives into the base grease in the form of GO or h-BN for its tribological properties. The "Graphene paste" turned out to be "just as effective" as a grease containing a significant concentration of GO.

Keywords:

tribology, grease, graphene oxide, hexagonal boron nitride

Introduction

Graphene and other types of carbon nanostructures have long been the object of research of scientific centers around the world. They carry out various kinds of tests aimed at developing economical production methods of graphene materials and their application in a wide range of technical fields. The interest in graphene is due to its unusual electrical, mechanical, thermal, optical and chemical properties, which make these nanostructures a potential substitute for many currently used materials such as silicon and steel. Currently, the main obstacle to the widespread use of graphene materials is the difficulty in their production, which prevents the industrial production of high-quality graphene. Another problem is the cost of obtaining graphene, which determines the high price of the substance, which means that its widespread use is currently uneconomical.

Tribology is one of potential areas for the use of graphene materials. The premise for undertaking research determining the tribological use of graphene is the structure of the particle, similar to the structure of solid lubricants, used as additives to oils and greases (graphite, hexagonal boron nitride, molybdenum disulphide) and its mechanical properties.

In the literature one can find several publications, which include the results of various tests determining the impact of introducing individual varieties of carbon nanostructures into the structure of friction-cooperating composite materials [1, 2], their use as protective coatings [3, 4] and the use of them as additives improving the tribological properties of lubricants [5-7]. The few results of studies on the introduction of graphene materials into lubricants indicate that their use contributes to lowering the coefficient of friction and to reducing wear of cooperating elements.

Basic information about graphene

The issues related to the properties, production methods and areas of application of graphene materials have already been devoted to many publications [3, 4, 8, 9-17], including also the last publication of the author [18], therefore only the basic information on this subject will be recalled in this work.

Carbon materials have long been the object of research of scientific institutes located all over the world, which results from the properties owned by these materials. One of them that has received the most attention is graphene. This term is usually understood as a single (1 atom thickness), a flat, hexagonal structure containing carbon atoms (Fig. 1A), however, in practice, structures of greater thickness (up to 10 atoms, called multi-layer graphene) are used much more frequently in practice and structures containing elements or functional groups other than carbon (e.g. oxygen groups in graphene oxide) (Fig. 1B), due to the difficulty in obtaining the perfect graphene structure while maintaining reasonable production costs. Attention should be paid to the similarities between graphene and graphite - the latter consists of individual graphene layers, similar to multilayer graphene. The difference between multi-layer graphene and graphite is represented by the material's electrical properties, changing significantly with the thickness of 10 layers everything above this limit is considered graphite [19].



Fig. 1A. Structure of graphene; 1B. Structure of graphene oxide Source: [20, 21]

The characteristic feature of graphene structures are the bonds occurring in them: strong and short covalent bonds between carbon atoms in the horizontal plane and weak van der Waals bonds occurring in the direction perpendicular to the surface (Fig. 2A). It is worth noting that the structure of multi-layer graphene is very similar to the structure of hexagonal boron nitride (Fig. 2B), hence its selection for comparative research as a reference material in relation to graphene oxide.



Fig. 2A. Structure of multi-layer graphene; 2B. Structure of hexagonal boron nitride Source: [22, 23]

The bonds shown in Fig. 2 determine the extraordinary electrical (mobility of electrons at the level of $2*10^5 \text{ cm}^2/\text{V*s}$), thermal (thermal conductivity at the level of 1500-5300 W/m*K), optical (transparency approximately 97.7%) and mechanical properties of graphene (strength about 200 times greater than steel), thanks to which it can be used in many different areas of technology, such as electronics, composite materials, medicine and many others. Graphene can be used, for example, in [11, 12]:

- 1. sports equipment, e.g. tennis rackets;
- 2. energy storage;
- 3. medicine, e.g. in the delivery of drugs as a platform for transporting drug particles and antibodies to relevant cells of the body;
- 4. in antibacterial dressings;
- 5. transistors and capacitors;
- 6. light and durable body parts for vehicles and building structures;
- 7. gas detectors;
- 8. many other areas of life and areas of study.

The properties of individual graphene materials depend on the thickness of the structure, the content of elements other than carbon and structure ordering, which depends on the method of production used.

Graphene applications in tribology

Graphene materials, as it has already been mentioned, have long been a subject of research regarding the possibilities of their application in many different areas of technology. One of them is tribology, in which the influence of graphene on improving the properties of friction nodes is analyzed, by:



- 1. introduction of graphene materials into lubricants [3, 5-7, 24-29];
- 2. applying graphene materials as protective coatings [3, 4];
- 3. the use of graphene materials in composite materials [1, 2].

Based on the above publications, it can be concluded that the most common research was in the field of using graphene and its varieties as an additive improving the tribological properties of lubricants, such as oils and greases. The results that can be found in the literature indicate that the introduction of graphene materials into lubricants generally has a positive effect on their tribological properties, reducing the coefficient of friction and wear value.

The issue of the influence of the introduction of graphene materials into greases is described in [7]. It analyzed the value of the coefficient of friction on a dedicated station for samples containing 0.5%, 1%, 5% and 10% (w/w) of multi-layer graphene under the loads 5 N, 10 N and 15 N. The obtained results indicate that the introduction of larger amounts of graphene into the grease contributed to the reduction of the coefficient of friction. Fig. 3 presents the average values of the coefficient of friction for individual samples, taking into account all variants of given loads. A sample labeled "COMPOUND 1" means a sample of pure grease and the following numbers indicate an increase in graphene content.



Fig. 3. The average value of the coefficient of friction for individual graphene concentrations Source: [7]

The tribological properties of a grease containing various concentrations of carbon nanotubes (CNT) are also presented in [30]. It included the results of the research on lithium grease, in which nanotubes were introduced in concentrations: 0.5%, 1%, 2% and 3% by weight. Tests of tribological properties were carried out using the Conestoga four-ball apparatus, in accordance with the requirements of ASTM D2266, at 75 °C, at a rotational speed of 1200 rpm, during 30 minutes. The studies were carried out under loads 100 N, 200 N, 300 N, 400 N and 500 N, which corresponded to pressures of 2.78 GPa, 3.49 GPa, 3.99 GPa, 4.39 GPa and 4.73 GPa. During the tests, measurements of the coefficient of friction and wear scar diameters (WSD) of balls were made, and the obtained results are shown in the Fig. 4. According the figure below, it can be observed that the introduction of carbon nanotubes into the grease brought about a significant improvement of its tribological properties in the case of small additive concentrations. The most favorable friction coefficient values and the smallest diameters of wear scar were obtained for samples containing 1% CNT. According to the drawing, the introduction of larger quantities of carbon nanotubes into the grease did not contribute to further improvement of tribological



properties, and bringing the opposite effect - the friction coefficient for the sample containing 3% CNT was similar to the results obtained for pure lubricant [30].



Fig. 4. Friction coefficient and wear scar diameter (WSD) as a function of CNTs concertation Source: [30]

The properties of graphene materials, briefly described above, their structure (similar to solid lubricants such as graphite, h-BN, MoS_2) and incomplete and often divergent results of research published in the literature [1-7, 24-31] were the prerequisites for undertaking research on tribological properties of greases contained graphene oxide. It seems that in tribological use, this structure can show better efficacy than pure graphene.

Experimental methodology

In this part research, multi-layer GO graphene oxide, made using the modified Hummers method (Fig. 5A), was produced by the Institute of Electronic Materials Technology (ITME) in Warsaw [32]. In addition, hexagonal boron nitride h-BN (Fig. 5B) was used as a comparative material in relation to graphene oxide.



Fig. 5A. Graphene oxide; 5B. Hexagonal boron nitride Source: own source



The reference material that was used in these studies was hexagonal boron nitride, also called "white graphite", produced by the Military University of Technology. Its structure, similar to graphite, makes it a very good addition improving the tribological properties of oils and greases [33]. This substance is characterized by considerable chemical and thermal stability and is also safe to use. The characteristics of both additives are shown in Tab. 1 and 2.

Parameter		Unit of measure	Value	
Aŗ	opearance	-	From light brown to dark brown.	
Volu	ime density	[g/cm ³]	~0,2	
Specific Surface area		[m ² /g]	5 (spray drying) 11 (vacuum freeze drying)	
Solubility in H ₂ O		-	It forms a homogeneous suspension.	
Content of ingredients	Carbon		40÷42	
	Oxygen		45÷52	
	Sulfur	%	1÷3	
	Nitrogen		<0,3	
	Hydrogen		2,5÷3	

Tab.	1.	Characte	eristics	of	graphene	oxide
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Source:	[32]
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Tab. 2. Characteristics of hexagonal boron nitride

Parameter	Unit of measure	Value
Density	[g/cm ³]	2,000÷2,355
Hardness on the Mosh scale	-	1÷2
Thermal conductivity	[Ωcm]	1014
Melting point under nitrogen pressure	[°C]	3000
Infrared spectrum	[cm ⁻¹]	1390 i 810
Oxidation temperature	[°C]	>1000
The size of grains	[µm]	<2 (average ~0,6 µm)

Source: [33]

The substances described above were introduced into the grease base of consistency class 2 according to the NLGI (National Lubricating Greases Institute) classification. Grease base was produced by the Research and Analytical Center of the Czechowice-Dziedzice Refinery, on a special order [34]. The base was stored in a sealed metal container, and its selection was conditioned by its availability and its purity (no additives). According to [34], the base was characterized by a density of 0.883 g/cm³ and a penetration of about 270.

The following grease samples were prepared for the tests:

- 1. Containing 0.01%, 0.1%, 0.5%, 1% and 2% (w/w) of graphene oxide GO.
- 2. Containing hexagonal boron nitride h-BN in concentrations of 0.05%, 0.1%, 0.5%, 1% and 2% (w/w).

The preparation of the samples consisted in measuring the appropriate amount of the substance, to which the appropriate amount of the grease base was then introduced in order to obtain the appropriate concentration. The sample was then heated to approximately 80°C (to avoid separation of the oil from the thickener) and subjected to manual stirring for 15 minutes. The heating and



mixing process was carried out three times to obtain a homogeneous mixture. The mixed sample was left to cool to room temperature.

In addition, a sample of the so-called "graphene paste", obtained from the Institute of Electronic Materials Technology in Warsaw, was also tested. "Graphene paste" made from the previously described graphene oxide (Tab. 1), dissolved in water at a concentration of ~ 4.5% (w/w) [32].

The tests of tribological properties of grease contained various concentrations of GO or h-BN were carried out using the following devices:

- 1. Four-ball apparatus T-02 (produced by the Institute for Sustainable Technologies in Radom) (Fig. 6A), on which the normative parameters P_t and G_{oz} were examined as well as the non-normative p_{oz} parameter (description in Tab. 3).
- 2. Universal nanomicro tribotester UNMT (produced by CETR, CA, USA) (Fig. 6B), on which the value of the coefficient of friction and wear value of the reference plate and the balls were measured.



Fig. 6A. Four-ball apparatus T-02; 6B. Universal nanomicro tribotester UNMT Source: own source

Parameter	Description	Model
G _{oz}	Wear limiting load capacity was calculated after the run lasting 60 ± 1 seconds, with a load of 147.10 daN (150 kg), which caused that the set pressure at the contact point was 5352,6 MPa. The top ball rotational speed during the test is 500 rpm.	$\begin{split} G_{oz} &= 0.52 \ \text{P/d_s}^2 \ (1) \\ \text{where:} \\ G_{oz} &- \text{ wear limiting load capacity } \\ [daN/mm^2]; \\ P &- \text{ set load [daN];} \\ d_s &- \text{ the average diameter of the wear } \\ \text{defects on the three lower balls [mm].} \end{split}$
Pt	Seizing load is the lowest (smoothly increasing) load, during which after time t the abrupt increase of friction torque in the system occurs. The measurement consists in setting a 0 N load on the lever, which increases at a speed of 409 N/s, with a top-ball speed of 500 rpm.	$P_t = t * 409 \text{ N/s} $ (2) where: $P_t \text{- seizing load [N];}$ t - time [s].
p _{oz}	Parameter reflecting surface pressure in the friction node after the test. The measurement was an extension of the P_t tests (due to the small amount of GO owned), which were not interrupted at the moment when the friction torque peak was reached, until the maximum permissible load of 784,53 daN (800 kg) was obtained on the device, at which the apparatus he switched off automatically.	$p_{oz} = 0.52 P_{max}/d_s^2 \qquad (3)$ where: $p_{oz} - parameter reflecting surface$ pressure in the friction node [daN/mm ²]; $P_{max} - maximum set load [daN];$ $d_s - the average wear scar diameters onthe three lower balls [mm2].$

Tab. 3. Parameters measured on a T-02 four-ball apparatus

Source: [33]



All tests were carried out in the Department of Tribology, Surface Engineering and Logistics of Service Fluids, the Faculty of Mechanical Engineering of the Military University of Technology.

Results and discussion

The results of the G_{oz} parameter tests are presented in Fig. 7. Fig. 8 shows the results of the P_t parameter.



Fig. 7A. Diameters of wear scar on the balls for different concentrations of additives during the G_{oz} test; 7B. The value of the G_{oz} parameter for different concentrations of additives Source: own source

According to the results presented in Fig. 7, it can be concluded that:

- the addition of up to 0.5% by weight into the grease did not bring significant changes compared to the properties of basic grease;
- further increase in the amount of additives into the grease (1% and 2% concentration) brought noticeable changes in the diameters of the wear scar of the lower balls, translating in more favorable values of the G_{oz} parameter;
- the value of the wear scar and the G_{oz} parameter for the graphene paste was similar to the results of the sample containing 1% (w/w) h-BN a 22% improvement over the basic grease;
- the best results were obtained for a sample containing 2% GO the G_{oz} parameter value increased by 180% in relation to the basic grease (an increase of 131% for the 2% h-BN concentration);
- in the case of small concentrations of additives a more beneficial effect was observed for samples containing h-BN.







In the case of Pt (Fig. 8A) parameter measurements, it was found that:

- introduction of both types of additives into the basic grease influenced on the improvement of the analyzed parameter;
- the most favorable results were obtained for samples containing GO (improvement 203% for a sample containing 1% GO and 169% for a sample containing 2% GO);
- results obtained for "graphene paste" were better than for samples containing h-BN, but worse than for samples containing GO.

In the case of poz (Fig. 8B) parameter measurements, it was found that:

- samples containing h-BN were characterized by worse values of the tested parameter in relation to the sample of the basic grease (decrease by 3% for 1% h-BN concentration and decrease by 8% for the concentration of 2% h-BN);
- results obtained for "graphene paste" were worse by 5% in relation to the basic grease;
- GO-containing samples were characterized by a slightly better value of the tested parameter (an increase of 2% for 1% GO and an increase of 1% for 2% GO).

The reversal of the tendency of changes of p_{oz} parameter in relation to P_t , in the case of h-BN, could be influenced by easier centrifugation of h-BN particles, due to its 10 times higher density than GO, while the load continues to rise smoothly after exceeding P_t . Significantly less symptoms of this type were also demonstrated by GO. In other words, GO showed greater resistance to seizing, under the test conditions on a four-ball apparatus. The results obtained for the "graphene paste" samples are, similar to the G_{oz} parameter, close to the results obtained for a sample containing 1% h-BN.

In order to supplement the results of the tests obtained on a four-ball apparatus, additional tests were carried out on the UNMT nanomicro tribotester. The characteristics of test conditions are presented in table 4. The load was selected so that the set unit pressure (5323,6 MPa) in the contact zone of the ball with the plate was close to the pressure used in the G_{oz} parameter evaluation on a four-ball apparatus (5352,6 MPa) [35]. The results of the tests on the UNMT nanomicro tribotester are presented in Fig. 9 and 10.

	Tab. 4.	Parameters	measured	on a	UNMT	nanomicro	tribotester
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Parameter	Unit of measure	Value
Kind of montrion	-	reciprocating
Load / Pressure	[N] / [MPa]	150 / 5323,6
Amplitude	mm	1
Frequency	Hz	25
Total number of cycles	-	22 500
Linear speed	mm/s	50
Time of test	min	15

Source: own source



Fig. 9A. Diameter of wear scar on the balls for individual concentrations of additives; 9B. Width the wear path on the plate for individual concentrations of additives







According to the results presented in Fig. 9 and 10, it should be stated that:

- introduction of each amount of h-BN into the basic grease contributed to reducing the diameter of the wear scar on balls, of which the best results were obtained for the sample containing 2% h-BN (43% decrease compared to the basic grease);
- introduction of up to 0.5% of GO to basic grease in a similar effect, however, further increase in GO content in the sample increased the diameter of the scar wear on the balls;

- the worst results were obtained for samples containing 2% GO (increase in the diameter of the scar of wear scare on balls by 17% in relation to the sample of basic grease and increase in the width of wear path on the plate by 19%) and for "graphene paste" (increase in the diameter of the scar of wear the ball by 20% in relative to the sample of basic grease and increasing the width of wear path of the plate by 24%);
- the addition of 1% any additive to the basic grease did not bring any changes in the coefficient of friction compared to the basic grease, however increasing the h-BN content to 2% made a slight improvement (decrease in the coefficient of friction by 6%), and in the case of GO worsening (increase in the coefficient by 25%);
- the value of the coefficient of friction during the test was the most stable for the sample containing 2% h-BN and for the basic grease, while for samples containing graphene oxide this value was constantly changing, which was particularly evident in the case of "graphene paste".

Conclusions

According to the results of the conducted research it can be concluded that:

- In the case of G_{oz} parameter measurements, it was found that the addition of additives to the concentration of 0.5% does not cause significant changes in the diameter of the wear scar of balls. On the other hand, for concentrations of 1% and 2% GO and h-BN, a clear decrease in diameters of the wear scar was visible, meaning an increase in the G_{oz} parameter. The results obtained for "graphene paste" were similar to the results for samples containing 1% h-BN, and the best results, relative to the basic grease, were obtained for a sample containing 2% GO.
- In the case of measurements of the P_t parameter, samples containing GO and the "graphene paste" sample showed much better results than those containing h-BN.
- In the case of p_{oz} parameter measurements, also more favorable results were obtained for samples containing GO and for the "graphene paste" sample.
- In the case of diameter of the wear scar on the balls and the wear width of paths on the reference plates obtained in tests on the UNMT nanomicro tribotester, it was found that up to 0.5% of both additives only slightly decreased compared to the basic grease, while at concentrations of 1% and 2% more favorable results were obtained for samples containing h-BN. Interestingly, for samples containing a significant amount of graphene oxide (2%, "graphene paste"), the wear scar on ball and plate wear were greater than for a basic grease.
- In the case of measurements of the value of the coefficient on the nanomicro tribotester UNMT, it was found that the introduction of GO and h-BN to 1% concentration does not cause visible differences in changes of this parameter, however at a concentration of 2% the sample containing GO showed an increase in the coefficient of friction, in contrast to the sample containing h-BN, in which the coefficient of friction decreased.
- The results obtained for samples containing a relatively high content of graphene oxide (2% GO (w/w), "graphene paste") showed the improvement of tribological properties in the case



of tests for rotary motion, however, they were definitely worse for reciprocating motion tests it may be result from the formation of agglomeration of graphene particles that enhance the scratching of cooperating surfaces.

It should be noted that the conducted tests are preliminary (due to over small amounts of GO), and the obtained results are subject to measurement uncertainty, therefore, a larger number of detailed tests should be performed on different tribiotesters and for different, also increased, GO contents. Such tests are planned and will be implemented in the near future, including bench testing of rolling bearings. It is also very important to examine the impact of GO content on other standard properties of the grease.

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LEMKO CULTURE AS AN ELEMENT OF THE REGION'S PROMOTION

Katarzyna Dudzińska*, Elżbieta Wilczyńska, Karolina Babiarz, Dobrochna Dara, Ewelina Dyląg

Studenckie Koło Naukowe Podróżników, Wydział Wychowania Fizycznego, Uniwersytet Rzeszowski, Rzeszów * corresponding author: kasia0911@onet.pl

Abstract:

For over twenty years, Lemko culture has been at the center of interest. We learn about the culture of an interesting ethnographic group not only from written narratives, but also from verbal narratives. The basic source of information at work was a query of the subject literature and available archival sources. The aim of this work is to present the Lemko culture as one of the elements of the region's promotion including the Lower Beskids and Beskid Sądecki. The main problem was the statement: How does the Lemko culture affect the contemporary promotion of the region? The aim was to get answers to the following research questions: Are there any monuments that testify to the existence of this culture? Are the elements of the material culture of the group used in everyday life? The work presents the material and immaterial culture of the Lemkos, as well as monuments incorporated into the rural landscape of selected areas on which the Lemkos settled.

Key words: culture, Lemkos, promotion of the region, Lemko culture

Introduction

For over twenty years, Lemko culture has been at the center of interest among researchers in social sciences and the humanities. The shortcomings in studies related to the present day group make it difficult to create a clear picture of the Lemkos from the moment they appeared in Poland until the 21st century.We learn about the culture of an interesting ethnographic group not only from written narratives, but also from verbal narratives, from interviews and diaries conducted by the Lemkos, who returned to the area of today's Lemkos, after they were displaced from their native lands as a result of the Operation Vistula.

The scope of research on Lemko culture has been described on the basis of many years of research conducted by an outstanding ethnographer and expert on Polish folk art Roman Reinfuss.

In his work, the author discusses problems related to the appearance of Lemkos in Polish lands, material, social and spiritual culture as well as monuments of Lemko culture incorporated into the image of contemporary villages of the Lower Beskids and Beskid Sądecki.



Objective of the work, subject of research, research problems

The basic source of information at work was a query of the subject literature and available archival sources.

The aim of this work is to present the Lemko culture as one of the elements of the region's promotion and to protect the studied ethnographic group from oblivion.

The main problem in this work was the question: How Lemko culture influences the contemporary promotion of the region. The aim was to get answers to the following research questions: Are there any monuments that currently testify to the existence of this culture? Are the inhabitants aware of the remains of the Lemkos in the areas of the Lower Beskids and Beskid Sądecki? Are the elements of law, material and social culture currently used in everyday life?

Method, technique and research tools

The work uses the induction-deduction method and then comparative method. In addition, a query of the literature of the subject and archival sources, as well as written and oral reports were conducted.

Lemkos - general characteristics

"This people lives in the Lower Beskids from the sources of Ropa to the sources of the San River. In their dialect we find the word: "łem" meant only in some villages of Osława: "nem" so they are called Lemkos. They call themselves Rusnaky "[1].

There are many theories on the origin of the Lemkos. Some think that they originate from Wallachian colonization, which originated from present-day Romania and between the 14th and 16th centuries dominated the main chain of the Carpathians on the Polish side, ie.Bieszczady, the Lower Beskids, BeskidSądecki, and Morawy [2].

According to K. Dobrowolski, this people were anxious, and because of that were prone to robbery. His wanderings took place in spring and autumn through agricultural areas. This situation could have an impact on the nomadic shepherds, leading them on the northern side of the Carpathians to lead a sedentary lifestyle [3].

Another theory is that the Lemkos belong to the descendants of the Croats (White) and for centuries they were inhabitants of the Carpathians, who covered the territory of Krakow and the Tatry Mountains together with eastern Slovakia. The third concept assumes that it was a Thracian shepherd people, leading a nomadic lifestyle until the end of the 14th century [2].

Lemkos inhabited hard-to-reach areas, which were areas overgrown with primeval forests with infertile, rocky soils. The first mentions of settlement in these areas come from the 12th century, they are information about the villages at the confluence of the rivers Wisłoka, Ropa and Jasiołka [4].

In the 13th century, the first information about the villages that belonged to the Lemkos region appeared. One of them was Muszyna, which in 1288 was donated to the bishopric of Krakow. The second town was Nowe Miasto (later Tylicz). The period of the largest population of the later Lemko region dates back to the 14th century, when during the reign of Casimir the Great, the Red Ruthenia was incorporated into Poland [4].



The name Lemkos

The people of the Eastern rite from the Lower Beskids and parts of the West Beskid called themselves "Rusnaky". The name "Łemko" (plural - Łemky) comes from the Slovak word "lem" - only, but. The word "Łem" amused the borderland population called Boykos from behind the Wielki Dział and they called the closer western neighbors of "Łemkamy". Authors writing about the population of the Lower Beskids in the 19th century (including A. Toroński) extended this nickname to the entire western group of Ruthenian highlanders [4].

For the first time the name Lemko was used by Osyp Lewickij in 1834, and in 1837 it was repeated by Szafarzyk in the work entitled "Slavic antiquities" [5].

The name "Lemko" first existed as a nickname and was introduced to the scientific literature by Jan Caplovic in 1820. It defined the then Rusyns, inhabiting the southern part of the Carpathians. Considering the Galician Rusyns, who now call themselves Lemkos, he used that name in 1831. Josyf Łewyckij (Krosno 2012) [6].

The name "Lemko" was used already in the eighteenth century, but it was not older than the name "Rusnak" from the 16th century. From the 19th century, the Lemkas used the name "Rusin" and "Rusnak" alternately with a new one. After the Second World War, the name "Lemko" became stronger [6].

Currently, the name "Lemki" is popular in Sądecczyzna in the Gorlice poviat and in the central Lemkovyna, more or less after the Dukla Pass. The farther east - the Lemkos are less known. [5] However, it should be noted that the Lemko culture has not completely disappeared. A lot of families, especially Orthodox, have kept separate and aware [1].

Chyże

"Chałupy", which were called chyże are characteristic mountain huts. Under one roof, there was a living room and utility rooms. These were rooms such as:hall, chamber, pitch, stable. With time, in a newer or richer time, the room was divided into an alcove. It happened that in the huts, windows were put into the chamber next to the hallway, which turned into a living room called a chyżka [7].

The chamber was a room for farm equipment: grain for corn, barrels for sauerkraut, small dishes, etc., as well as a chest that kept clothing for the holidays. The chamber was also used for primitive box beds, which were slept in the case of a large family [8].

The beams of the cottages were mostly painted in red, including from milky-strawberry to dark-beetroot, and the gaps between the beams were whitewashed with lime [7].

The barns (gates from the pitch) were painted yellow. Painted circles, flowers or dots were painted on the corners [9].

The doors and windows were yellow and the window frames were green or blue [8].

The doors and gates on the pitch were decorated with lime in stripes having the shape of a wavy line, floral or geometric motifs [8].

Around the windows and doors there were blue borders or plant ornaments. The walls for the winter were sealed with straw, and the cracks in the construction of the house were clogged with



moss from the forest. The roofs were covered with straw, which had to be evenly cut and twisted in the so-called kyczky (sheaves of straw for covering the cottage). They were stacked on top of each other and resembled stairs [9].

Selected churches preserved to this day

Church (in polish: Cerkiew) - from Greek, belonging to the Lord. In the 16th century, in the Polish language, all churches as well as synagogues were called this. In the seventeenth century, there is a definitive division in terminology, the church remains Orthodox and Uniate [10].

The Lemko churches have a log construction. Long, debarked wooden logs were laid on each other, connected in corners by means of special incisions. Originally, only one entrance from the western side led to the church. In the oldest Lemko churches, window openings in the walls of the nave and presbytery were only on the southern side. The construction of the Lemko church was based primarily on the principle of tripartite (presbytery, nave, and women's gallery) [11].

Currently, there are about 110 churches. Inscribed on the UNESCO list:

- Brunary Wyżne: Greek Catholic Orthodox church dedicated to St. Michael Archangel, currently a Roman Catholic church dedicated to Of the Assumption of the Virgin Mary. It is dated to 1797. The building, despite its later transformations, has preserved the most important features of the West-Pomeranian church. The interior is topped with flat ceilings with facets. The polychrome of Rococo and classicist architectural and plant motifs were made by Antoni and Józef Bogdański in 1898. The nave features fragments of the older baroque polychromy from the late 18th century. Baroque iconostasis from the 18th century was repainted during the renovation in 1831. It was inscribed on the UNESCO World Cultural and Natural Heritage List [12].
- Kotań: Greek Catholic Orthodox churchdedicated to SS. Kosma and Damian, currently Roman Catholic churchdedicated to St. Anthony of Padua. This church is one of the most representative examples of UNESCO's ancient west Lemkos religious architecture. The church was built in 1782 [13].



Fig. 1. Church in Kotań Source: [14]



- 3. Kwiatoń: Greek Catholic Orthodox church dedicated to St. Paraskevia, currently a Roman Catholic church dedicated to Our Lady Queen was established in the second half of the seventeenth century. The temple is a classic example of Lemko church architecture. Because of its proportions, it is considered one of the most beautiful churches in Poland. The decor of the interior is a polychrome with figural and ornamental motifs from 1811. The complete equipment has survived: iconostasis (wall with icons) from 1904, presbytery in the main altar from the nineteenth century, two side altars with icons of the Mother of God with the Child and the Descent from the Cross. In 2013 it was included in the UNESCO World Cultural and Natural Heritage List [15].
- 4. Owczary: Greek Catholic Orthodox churchdedicated to the Protection of the Blessed Virgin Mary, now a Roman Catholic church. A wooden West-Lemkos temple is one of the oldest churches in the Lemko region. UNESCO. Wooden Orthodox church. OpiekiBogarodzicy (Care of the Mother of God) is the oldest in the Lower Beskids area in the type of West Lemkos temples. It was built in 1653, from that period comes: nave and western portal, presbytery and sacristy. This is a typical example of the Gorlicka land for the intermingling of the cultures of East and West [16].



Fig. 2. Church in Turzańsk Source: [17]

Other churches

- 1. Turzańsk: Greek Catholic Orthodox churchSt. Michael Archangel A five-domes wooden church built in 1801-1803. It is crowned with five towers, which is unique and has no equivalent among wooden churches in the Lemko region [13].
- 2. Komańcza: Greek Catholic Orthodox church dedicated to the intercession of Our Lady built in the years 1800 - 1803. Represents the eastern type of Lemko churches. In 2006, on the eve of the Feast of the Protection of the Mother of God, the church was destroyed by fire. The new, reconstructed site was devoted in this place in 2010 [13].
- 3. Krempna: Greek Catholic church dedicated to St. Kosma and Damian, currently a Roman Catholic church dedicated to St. Maksymilian Kolbe. The church was built in 1778 using the material from the old temple from 1640. This is an example of a typical wooden church in the style of West Lemko. It consists of a presbytery, a wider nave and a woman's gallery,


above which a tower with sloping walls is erected. The charm of the temple adds the roofs and towers covered with shingles. On the walls there are icons made in 1664 [18].

- 4. Polany: Greek Catholic church dedicated to St. Jan Złotousty, now a Roman Catholic church dedicated to Our Lady of Częstochowa. A wooden Orthodox church erected in 1820. In 1946, it was renamed the Roman Catholic church and it still has this function to this day. The Orthodox church is in the classical style. Next to the church there is a historic belfry [19].
- 5. Zyndranowa: The Orthodox Church dedicated to St. Nicholas was created in the 1980s. Despite the fact that the temple was erected in the present time, it resembles a traditional Lemko Orthodox church. The Orthodox church survived both world wars. In 1962, after returning from the deportation, the Lemkos demolished their temple due to its poor condition. Before demolition, the residents obtained the assurance of the then authorities that they would get permission to build a new church [20].



Fig. 3. Church in Zyndranowa Source: [21]

Tourism in the Lemkovyna

The phenomenon of this beautifully landscaped area are the remains of the material and spiritual culture of its inhabitants, which were and still are the Lemkos. An inseparable element of the landscape are churches, shrines and roadside crosses. The largest Museum of Folk Architecture with a collection of Lemko architecture is in Sanok, and the second is the Private Museum in Zyndranowa [22].

According to surveys conducted among students of geography of the Jagiellonian University, the Low Beskids is one of the most visited places by students of mountain groups, because it is characterized by clean water, clean air and enables direct contact with wild nature.

In terms of history and culture, this area is distinguished in particular by:

- sacral architecture, secular architecture and the former spatial arrangement of the village and folk architecture,
- places rich in souvenirs related to historical events,
- industrial facilities that are associated with the natural wealth of the region,



- preservation and observance of certain folk rituals and customs,
- the presence of national minorities,
- spas,
- a small number of settlements and a low degree of urbanization [22].
- Museum of Folk Architecture in Sanok

The Folk Architecture Museum in Sanok was established in 1958. This monument was to protect and present the buildings of south-eastern Poland, which were inhabited by ethnic groups before the Second World War, such as: Boykos, Lemkos, Dolinianie, and Polish Uplanders. The park is located at the left bank of the San River [23].

The entire Park has an area of 38 ha. There is one of the largest permanent expositions of iconic paintings in Poland titled "Carpathian icon" [24].

Events that are organized in the park are: Folklore Fair, which is the oldest event in the open air museum combined with folklore performances, trade and art craft show, and Folk Summer Farewell (formerly Eurofolk), which has been organized since 1993 [23].

In the Lemko sector of the Park you can see, among others, buildings, granaries, farms and an Orthodox church from the turn of the 18th and 20th century [25].

Historical Museum in Sanok - an exhibition of Russian icons and the only Orthodox church in the city dedicated to the Holy Trinity. It was built in the years 1777-89, the bell tower was added in 1827. It could be proud of the relics of the Holy Cross and a wonderful icon of Our Lady of Grace, which was transferred to the Franciscan Church and are there until now [26].

Regional chamber in the Complex of Schools in Komancza - there are Lemko souvenirs with everyday objects of the inhabitants of the village [27].

Embroidery Museum in Komańcza- The Museum is currently run by Mrs. Boiwka, in one of the rooms in a private apartment. You can see in it a collection of men's and women's clothing from Lemkos, both intended for everyday duties and holidays.

Summary

The work presents the most important selected elements of the material and immaterial culture of the Lemkos, as well as monuments incorporated into the rural landscape of selected areas on which the Lemkos settled. The main purpose of the work was to present the Lemko culture as an element of the region's promotion, thanks to the subject literature, available archival sources and interviews with the inhabitants of the commune, who returned to their homeland after the Operation Vistula.

The Lemko culture is a living culture, as evidenced by, among others:

- a private collection of costumes and embroideries,
- the Lemko sector in the Museum of Construction in Sanok,
- Lemko Museum in Zyndranowa,
- roadside crosses and chapels and old tombstones of the Orthodox cemeteries,
- publishing books and folders containing information about Lemkos living in the Low Beskids,



- songs of Lemkos sung by older inhabitants of the village,
- learning to embroider images in schools and farmer's wheels,
- the annual Jordan Day, celebrated at the wonderful Spring in Radoszyce and Komancza,
- cultivating Lemko beliefs and customs, eg in Wisłok Wielki, the first Christmas Eve dinner in some homes is garlic with salt, the house houses hazel twigs, during Christmas carolers walk around the houses, in Christmas the woman can not cross the threshold of the apartment as first, the child has a tied red ribbon to a teat or pram to avoid spells, removing spells by spitting and soaking charcoals, faith in the death announcement by howling the dog, etc.,
- it is becoming more and more popular to restore old houses along the lines of Lemkos, as evidenced by the old cottage in Wisłok Wielki– Cottage by the Wisłok [28].

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FUEL INFRASTRUCTURE IN POLAND

Tomasz Filipiuk

Military University of Technology, Faculty of Mechanical Engineering, 00-908 Warsaw, ul. gen. Sylwestra Kaliskiego 2 corresponding author: tomasz.filipiuk@wat.edu.pl

Abstract:

The liquid fuel infrastructure in Poland consists of many elements and objects that together form a network of interconnected cells as part of the operation of one liquid fuel supply chain. Currently, the liquid fuel infrastructure in Poland consists of refineries, fuel bases and terminals as well as fuel stations, both public and company ones. Transport is connection between all elements of infrastructure. The displacement of fuels from refineries to fuel bases takes place via long-distance pipelines and rail transport. Transport from petrol bases and terminals to petrol stations is performed using road tankers. Fuels intended for consumption in the country may come from own production, i.e. from refineries and from imports. Fuel imports in Poland are carried out by means of rail and sea transport. The aim of the article is to present what the liquid fuel infrastructure in Poland looks like and whether its condition is sufficient in relation to the needs of the country.

Keywords:

liquid fuels, fuel infrastructure, transport, fuel base

Introduction

In Poland, the turnover of fuels includes products resulting from the processing of crude oil, which constitute the majority of fuels consumed in the country and biofuels produced from renewable energy sources. Currently, biofuels are used to a small extent due to the fact that their production is expensive, and the application does not bring the appropriate benefits. In addition, the use of biofuels as an intrinsic fuel in vehicle engines, currently produced, involves making some changes both in the construction of these engines and in fuel supply and supply systems. Although European Union regulations require biofuels to be used in transport at the level of 8.0% (in 2019) in relation to the total number of renewable energy use, their practical application is based on the addition of biofuels to petroleum fuels. In connection with the above, fuels resulting from the processing of crude oil are now and in the near future will be used to power road vehicle engines. In this way, it is necessary to properly use the fuel infrastructure owned by Poland together with maintaining it in a proper technical condition in order to use it as long as possible. The expansion and creation of new fuel infrastructure is also important.

The fuel infrastructure includes refineries, bases and pallets terminals as well as fuel stations. Refineries add fuel for production of crude oil, which in Polish conditions is imported in



approximately 96,4%, of which 76,0% comes from Russia, and approximately 3,6% from domestic production (data for 2018) [1]. From the refinery, fuel are transported to fuel bases and terminals, which are a kind of distribution centres for fuels from which liquid fuel are transported to a petrol station. Fuel bases and terminals are characterized by the fact that they are able to store large amounts of fuel in appropriate conditions. Fuel bases are responsible for taking fuel from refineries and importing, storing and dispensing of these fuels for various types of transport. From fuel bases and terminals, liquid fuel are transported to a petrol station, where tanks for motor vehicles are refueled. Between these facilities, there is transport that is necessary for the proper functioning of the country's fuel infrastructure. From refineries to fuel bases and terminals, liquid fuel are transported by pipeline and rail transport. However, road transport is used for transporting fuels from terminals and terminals to service stations. In addition, it should be noted that petrol stations can be directly transported to petrol stations from the refinery by road transport. There are fuel bases that accept fuel from a pipeline or rail transport and forward it to other fuel depots using railway transport. Apart from fuels produced in refineries, imported fuels are also found on the domestic market. Fuel imports can be carried out by pipeline, sea and rail transport. In 2018, imported liquid fuels in Poland accounted for over 11 million m³ [1].

The fuel infrastructure of the country translates into the fuel economy of the country. The country's fuel economy is nothing more than having the right amount of liquid fuels on the domestic market to ensure the proper functioning of the state. When discussing fuel economy, reference should be made to fuel security, which is part of the energy security of the state. Both listed security contribute to national security. Fuel safety is based on maintaining adequate reserves of fuels, known as intervention stocks, which are responsible for the proper functioning of the state in the event of disruption of crude oil and petroleum products.

The analysis is aimed at showing what Poland's fuel infrastructure looks like at present, how it works and what its status is. The analysis shows how to expand the network of fuel pipelines in Poland and what areas need improvement. Attention was also paid to the problem related to the fuel security of the country and the maintenance of mandatory intervention stocks.

Characteristics of fuel bases

In Polish conditions, the terminal of liquid fuels should be understood as "a building facility for storage or handling of crude oil and petroleum products" [2]. Within the fuel economy of the country, the raw material bases responsible for the storage of crude oil and the liquid gas base are also distinguished. The bases of liquid fuels can be divided according to their purpose, size and safety, the construction of storage facilities and the type of operating system. The mentioned division is presented in Fig. 1.





Fig. 1. Classification of fuel bases Source: own study based on [3]

The diagram presented in Fig. 1 shows the division of fuel bases depending on four basic criteria. Taking into consideration the purpose of the fuel base, it can be divided into those that constitute an independent economic object and deal with supplying specific units. The first ones store large amounts of fuels for a longer period of time and are an essential element of the fuel economy. On the other hand, the latter deal with storing smaller amounts of fuels for the needs of specific units, e.g. a base of aviation fuels at lower-ranked airports or a fuel base near racetracks. The division for the sake of safety and the size of fuel bases is related to how large the fuel base is, e.g. how many oil products can be stored, and thus what a big fire and environmental hazard it creates. The size of the fuel base determining the fire hazard and the threat to the environment, what means that the greatest fuel bases are the most dangerous to environment. The division due to the construction refers to whether the fuel base is stationary or half-way. Fixed fuel bases have a fixed location, while field ones can change their place of functioning depending on their needs. In case of division due to the system of operation, fuel bases can be distinguished:

- reloading;
- company;
- central distribution;
- current supply.

Each fuel base, regardless of the above-mentioned criteria, may be land, sea and river.

Fuel bases and fuel pipelines in Poland

There are 49 fuel bases in Poland that have a significant impact on the functioning of the country's fuel infrastructure. Fuel bases located in the country belong to three basic fuel economy entities. The mentioned entities are:

• PERN SA;

• PKN ORLEN SA;



• Grupa LOTOS SA.

PERN SA and PKN ORLEN SA they also have fuel pipelines in Poland that allow you to pump fuel between the refinery in Plock and 8 fuel depots located in the country. The distribution of fuel bases and pipeline connections is shown in Fig. 2.



Fig. 2. Distribution of fuel bases and fuel pipelines in Poland Source: own study based on [1, 4, 5]

No.	Place	No.	Place	No.	Place	No.	Place
1	Koluczki	14	Norowko	27. Ostrów Wielkopolski	Ostrów	40	Piotrków-
1.	KOIUSZKI	14.	Пагежка		Wielkopolski	40.	Trybunalski
2.	Nowa Wieś Wielka	15.	Barycz	28.	Płock	41.	Poznań
3.	Boronów	16.	Grabowno Wielkie	29.	Radzionków	42.	Rypin
4.	Rejowiec	17.	Ugoszcz	30.	Sokółka	43.	Jedlicze
5.	Emilianów	18.	Dębogórze	31.	Świnoujście	44.	Sławno
6.	Skarżysko	19.	Małaszewicze	32.	Szczecin	45.	Gdańsk Rafineria
0.	Kościelne			52.	SECECCIII		
7.	Trzebież	20.	Bolesławiec	33.	Trzebina	46.	Gdańsk Airport
8.	Jastrowie	21.	Gdańsk	34.	Widełka	47.	Jasło
9.	Wola Rzędzińska	22.	Gutkowo	35.	Wrocław	48.	Czechowice
10	Kowico	23	Lublin	36	Żurowico	40	Warszawa Airport
10.	Kawice	23.	Luoini	50.	Zulawica	49.	Orlen Aviation
11.	Zamek	24.	Mościska	37.	Koszalin		
12	Zawadówka	25	Nowa Sól	38	Legginy	{	
12.		25.	Ole-anias	20	Lygajiiy	{	
13.	Strzemieszyce	26.	Oiszanica	<i>5</i> 9.	Ivitawa		

Tab. 1. Location of fuel bases from the map in Fig. 2

Source: own study based on Fig. 2

Fig. 2 presents the distribution of fuel bases and fuel pipelines throughout the country. Additionally, Tab. 1 shows distinctly places where the fuel bases are located. In addition, the location of two major refineries in the country of Plock and Gdańsk was presented. As it results from the map presented, most fuel bases are located on the southern part of the country, which was



marked as the "largest concentration zone". Four pipelines of pipelines go out from the refinery in Plock, which together form a connection with 8 fuel depots. The pipelines are directed in four directions: east, south, south west and west. The pipeline towards the south-west belongs to PKN ORLEN SA, and the remaining three threads to PERN SA. The exact parameters of the pipelines are presented in Tab. 2.

Pipeline route	Length, [Km]	Capacity, [million tons / year]	Year of commissioning for operation
	PERN SA		
Płock – Koluszki	112	3,8	1968
Koluszki – Boronów	153	1,0	1992
Płock – Mościska	163	1,15	1970
Mościska – Emilianów	105	1,10	1975
Płock – Nowa Wieś Wielka	125	2,1	1983
Nowa Wieś Wielka – Rejowiec Poznański	83	1,4	1993
PK	N ORLEN SA		
Płock – Ostrów Wielkopolski	214	3,3	2002
Ostrów Wielkopolski – Wrocław	105	1,7	2011

	-	-				
Tab.	2.	Parameters	of	existing	fuel	pipelines

Source: own study based on [1, 4]

Table 2 presents individual sections of fuel pipelines located throughout the country. The dates given for the episodes to be used, their current bandwidth and length are given. It can be noticed that the pipeline section from Płock to Koluszki is the highest throughput and it is also the oldest section. The total length of fuel pipelines in Poland are 955 km. Looking at the throughput, only sections from Płock to Koluszki and Płock to Ostrów Wielkopolski allow to transport large batches of products in a relatively short time. As can be seen, there is a lack of fuel pipelines in the country that connect further fuel bases and allow Poland to connect with other countries.

Planned fuel pipelines throughout the country

Currently, there is an obvious lack of fuel pipelines in Poland that would allow relieving rail transport, and at the same time reduced the negative impact of transport of liquid fuels by rail on the natural environment. Currently, however, it is estimated that 50% of fuels from refineries to fuel bases and terminals are transported by rail and the same number of pipelines. In reality, however, only 8 fuel bases are connected to pipelines, which means that the majority of liquid fuels can be expected to be transported by rail. Fig. 3 presents the planned construction of pipeline sections in Poland.





Fig. 3. Network of planned fuel pipelines Source: own study based on

Fig. 3 presents existing and planned sections of fuel and raw material pipelines in the country. In addition, fuel bases between the sections of these pipelines and planned pipelines were presented. The following sections of product pipelines are planned:

- pipeline Płock Gdańsk would have a length of 240 km and its course would coincide with the raw material pipeline from Płock to Gdańsk. Additionally, in future it would be possible to connect fuel bases No. 11, No. 42, No. 39, No. 22 and No. 38 (numbering according to Fig. 2) to this pipeline. The construction of this pipeline should mainly involve Grupa LOTOS SA due to three fuel depots located near the planned pipeline line;
- pipeline Płock Małaszewicze refers to the planning of the Biernady Priłuki Małaszewicze pipeline route and would constitute a link between the refinery in Płock and the planned pipeline line. This pipeline line could also be built along the "Przyjaźń" pipeline using the same strip of land. In addition, this section could be connected to the fuel base in Emilianów;
- pipeline Plock Lublin is unlikely to be a venture, however, the creation of this pipeline would significantly improve the distribution of fuels in south-eastern Poland;
- pipeline Boronów Trzebina it would reduce the logistics costs of fuels in the area of the largest fuel consumption, e.g. Upper Silesia. This section would have a length of about 100 km and would connect the refinery in Płock with the Refinery in Trzebinia. In addition, it would be the first section of the pipeline connecting Poland with the Czech Republic where PKN ORLEN operates;
- pipeline Trzebina Ostrawa in the Czech Republic would connect Poland with the Czech Republic and thus join the Polish pipeline network with the Central European network;
- pipeline Wrocław Hartmannsdorf it would have a length of around 260 km and connected the refinery in Płock with the Leuna refinery in Germany. It would connect the Polish transport system with the German network;



- pipeline Rejowiec Poznański Schwedt it would also connect the Polish network of fuel pipelines with Germany, and its planned length is estimated at approximately 230 km;
- pipeline Nowa Wieś Wielka Gdańsk it would be an alternative to connecting Płock with Gdańsk and the planned pipeline from Płock to Gdańsk.

As it appears from the planned plumbing pipelines presented in the country, the sections that will combine fuel bases in Poland with refineries of neighboring countries have the greatest chances to be realized. At present it is difficult to say which of these investments will be started and successfully completed. A very good chance is for the pipeline to be built on the section of Boronów - Trzebina.

The fuel security of the country

The fuel security of the country is a very important factor related to the country's fuel economy. According [6] fuel safety of the country is "a state enabling current coverage of the demand of consumers for crude oil, petroleum products and natural gas, in a specified size and time, to the extent enabling the proper functioning of the economy". In order to obtain the indicated condition, it is necessary to maintain intervention stocks. This stock is maintained for the time when the supply of crude oil and petroleum products is disrupted. The intervention stock is the quantity of crude oil and liquid fuels, corresponding to the product of a minimum of 90 days and the average daily net transfer of crude oil equivalent in relation to the previous calendar year.

It is reported that the capacity of fuel bases for liquid fuels in Poland at the end of May 2016 was about 5,7 million m³. Storage capacity 2,609 thousand m³ was intended for intervention stocks, and approximately 3,100 thousand m³ for commercial stocks [7]. In 2015, only 60% of the storage capacity of fuel tanks in the country was used. These data come from the Information Materials Agency (ARM) information obtained on the base of information collected during symposia, industry conferences, as well as from entities dealing with the storage of liquid fuels. As of today these data may have changed, however, it is difficult to state unequivocally, because no specialist statistics are kept on this topic.

Knowing the above data on the volume of stored liquid fuels in Poland, it should be estimated whether the given capacity is adequate to the level of liquid fuel consumption in the country. POPiHN data shows that in 2016, the consumption of liquid fuels in the country amounted to 26 066 thousand m³ [8]. From this it appears that during the year almost fivefold trade in liquid fuels was recorded. Of this 2,609 thousand m³ should be intervention stocks. Considering the data on the consumption of liquid fuels in the analysed period and the fact that the intervention stock has to satisfy the economy for 90 days, it can be determined whether at a given level of consumption of liquid fuels it is possible for the state to function in the event of stopping supplies of liquid fuels and crude oil. 90 days is one quarter of the year, so the consumption of liquid fuels in 2016 should be divided by four. It can then be assumed that for 90 days in Poland, consumption should amount to 6,517 thousand m³ of liquid fuels. The maximum storage capacity of Poland is not adequate to requirement. However, in the case of intervention stocks, they are expressed in units of mass and in relation to oil equivalent.



However, the audit carried out by the Supreme Audit Office showed that the intervention stock is sufficient and even exceeds certain norms [7]. Referring to the data from 2016, the estimates shown how much intervention stocks should be. According to the monthly and semi-annual reports of ARM, the intervention stock of crude oil and liquid fuels converted to crude oil equivalent as at March 31, 2016 amounted to 6 677 thousand tone. According to these data, the level of intervention stocks was 104 days in relation to the 90 days required. Taking into account the data contained in [9] for the purpose of calculating intervention stocks for 2016, the average daily net transfer of oil equivalent (P) for the 90 days required for intervention stocks should be multiplied. For this reason, the following value of the intervention stock required in 2016 is calculated, which amounted to 5 188,2 thousand tonnes (57,98 thousand tonnes * 90 days). The intervention stock are actually owned by Poland was higher than required, resulting from international commitments. As at 31 March 2016, agency stocks according to the NIK audit amounted to PLN 1 654 thousand tonnes, while mandatory stocks amounted to 5 032 thousand tone. Trade inventories for the given control period amounted to 1 714 thousand. tons and secured an additional 27 days.

Following the calculation scheme adopted above, using the data of the Minister of Energy's announcement of 13 March 2018, where the average daily net transport of crude oil equivalent in 2017 amounted to 75,62 thousand tonnes, it can be calculated that the intervention reserve in 2018 should amount to 6 805,8 thousand tone. Is this level really compatible with the calculations, it is difficult to say because the data are not known, how many intervention stocks are maintained on both the ARM side and the entrepreneurs obliged to do so.

Conclusions

This article was intended to show how the country's fuel infrastructure in Poland looks like and how it is to the country's fuel security. As a result, the following final conclusions were formulated:

- 1. In Poland, there are obviously no additional sections of fuel pipelines connecting with each other fuel bases and refineries and fuel bases of other neighbouring countries. This state of affairs would allow Poland to export surpluses of produced fuels, but also to protect itself in the event of production breaks.
- 2. It is necessary to expand existing fuel bases so that the maximum fuel storage capacity is increased.
- 3. As part of the expansion of fuel pipelines, the refinery in Plock should be connected with the Gdańsk refinery, which will allow better management of surplus fuel or possible stoppages in production.
- 4. The NIK audit showed that Poland has a sufficient number of intervention stocks that will allow the country to function for a minimum of 90 days in the event of interruptions in the supply of crude oil and petroleum products.

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TOURISM AND ITS BENEFITS ON THE EXAMPLE OF SELECTED SPA HABITATS OF THE PODKARPACKIE REGION

Marcin Franczyk*, Diana Mazek, Karolina Łoś, Dominik Łoboda

Studenckie Koło Naukowe Podróżników, Wydział Wychowania Fizycznego, Uniwersytet Rzeszowski, Rzeszów * corresponding author: mmarcin9808@gmail.com

Abstract:

Spas can be places that go beyond the classic, medical orientation. Modern realities allow the use of such centers in the form of a definitely commercial center: leisure, recreational and tourist centers. The aim of the work is to analyze spas in Iwonicz Zdrój and Rymanów Zdrój. The tool used was a questionnaire independently prepared by the authors of this work. The survey technique used in the work was a questionnaire. 100 respondents took part in the study. On the basis of the conducted research, it can be stated that tourist traffic in the studied health resorts is generated at a high level. The condition of health resorts is conducive to the development of spa tourism.

Keywords:

Podkarpacie, spas, spa tourism

Introduction

Villages with healing properties are in line with the tendency of changes taking place in society. In the case of a modern citizen, there is a significant interest in health issues. Medical support is combined with the element of tourism and leisure, which are elements of the global functioning of the unit. As a consequence, the health resort should be viewed through the prism of three categories of health, tourism and leisure that are important for the whole society. Adoption of such an optics makes it necessary to pay special attention to the problems of health resorts - such places can play an important role not only for the users themselves, but also for the surrounding community. When discussing the problems of health resorts, it is worth noting that the potential of these places has not been fully used up to now. Spas can be places that go beyond the classic, medical orientation. Modern realities allow the use of such centers in the form of a definitely commercial center: leisure, recreational and tourist centers.

Concept

Spas are an extremely interesting topic. This results both from the diversity of such centers and the importance for maintaining health and well-being by people struggling with various types of ailments. Discussing the problems of spas should therefore begin with indicating the definitions in



force in this regard. An unambiguous conceptual framework allows for a precise reference to the other two elements related to the subject described, such as the functions and types of health resorts.

An important source that allows for clearly defined elements and structures used by the state are standards set by the Polish Committee for Standardization, Measurement and Quality. According to the norm prepared by this committee, a spa is to be understood as "an area having deposits of natural medicinal resources and a climate with medicinal properties or one of these factors, and spa treatment facilities and facilities as well as favorable environmental and sanitary conditions in which methodical treatment of specific diseases and in which leisure and tourist activities may be carried out ". According to the above-mentioned definition, it is necessary to emphasize significantly the treatment and infrastructural specifics - the above-mentioned norm thus fits in with the general European context of the perception and definition of health resorts [1].

The theoretical context, referred to in the framework of the above-mentioned conceptual norm concerning health resorts, should also be discussed in legal terms. In this respect, it is necessary to draw attention to the Act on spa treatment, health resorts and areas of spa protection as well as health resort communes. According to the wording of this legal act, a health resort should be considered as "the area where health resort treatment is carried out, separated for the purpose of using and protecting natural curative resources located in its area [2]. In addition, according to the aforementioned Act, a spa must have natural deposits of therapeutic raw materials, a climate with healing properties, a healing and relaxation infrastructure and proper development. Taking into account the legal context, it is necessary to emphasize the completeness in terms of the requirements that allow the area to be considered a health resort.

Characteristics of spas in Podkarpacie

There are four spas in the Podkarpackie province: Iwonicz Zdrój, Horyniec Zdrój, Rymanów Zdrój and Polańczyk. Each of them has a therapeutic profile established by the Minister of Health in line with the available therapeutic resources. In each of the four health resorts, treatment financed by the NFZ is possible. As for the nature of the Podkarpackie health resorts, three of them are foothill resorts (Iwonicz Zdrój, Rymanów Zdrój, and Polańczyk), and one is a lowland spa (Horyniec Zdrój). The following is a brief description of individual spas.

Iwonicz Zdrój

The spa in Iwonicz Zdrój is the oldest place of this type in Podkarpacie and one of the oldest in Poland. Iwonicz Zdrój lies at an altitude of about 410 m above sea level. in the Beskid Niski valley surrounded by small mountains. This area belongs to the Krosno Poviat, and Iwonicz Zdrój occupies 589 hectares. As far as population density is concerned, data from 2014 show that the commune of Iwonicz Zdrój has 10,982 people. Whereas the city of Iwonicz Zdrój in terms of the number of inhabitants is the smallest town in the poviat. The state for 2014 is 1852 inhabitants [3].

In the history of Polish remediation, Iwonicz Zdrój occupies one of the leading places when it comes to popularity among patients. The first mention of Iwonicz dates back to 1427, when the spa was in the possession of private hands. Information about the healing properties of water from these areas appeared in 1578. He was mentioned in his book "Cieplice" by Wojciech Oczka who is



a doctor of Stefan Batory [4]. The Statute of the Health Resort was granted to Iwonicz by the Provincial National Council in Rzeszów in 1973. The current statute, which has the municipality of Iwonicz, has been in force since 2009. For the protection of medicinal factors and raw materials, environmental values and spa facilities, three spa protection zones have been designated. What is extremely important in both zones A, B and C, the biologically clean area occupies about 90% of the entire area [5].

	Diseases		Treatments
٠	diseases of the nervous system: states after stroke,	•	individual and collective inhalations;
	multiple sclerosis, diseases of the peripheral nervous	•	mineral, acid-carbon, vortex, pearl, electric-water,
	system;		ozone baths;
•	musculoskeletal diseases: rheumatism, joint diseases,	•	individual and collective kinesitherapy;
	spine diseases, bone metabolic diseases, congenital	•	cryotherapy;
	malformations and acquired motor organs, conditions	•	laser;
	after spinal and limb injuries;	•	light therapy: Bio-V lamp, Solux lamp
•	digestive system diseases: stomach and duodenum,	•	massages: classic dry, underwater, pneumatic,
	bile ducts, intestines		Aquavibron;
•	respiratory diseases: chronic, inflamed pharyngeal	•	mud and paraffin wraps;
	mucous membranes and nasopharynx, chronic	•	mud patches;
	sinusitis, laryngitis, bronchi and tracheitis;	•	individual and collective gymnastics, water
•	diagnosis and treatment of osteoporosis;		gymnastics;
•	rehabilitation of women after mastectomy;	•	magnetotherapy, interdyn, intervac, diadynamics,
•	skin diseases: psoriasis, ichthyosis.		electroplating, terapuls, iontophoresis, ultrasounds,
			laser, sanotherm, tens;
		•	drinking cure with mineral waters (chloride-
			bicarbonate-sodium water, fluoride, bromide, iodide,
			boric acid, sulphide).

Tab. 1. Diseases treated in Iwonicz and treatments offered by sanatoriums

Source: own elaboration based on [6]

As part of the health resort of Iwonicz, there are currently 9 facilities providing treatment services for patients.

Rymanów Zdrój

Rymanów Zdrój is located at an altitude of 365 m above sea level. in the valley of the Tabor Beskid Niski river. This village belongs to the Rymanów Commune, which is part of the Krosno Poviat. The Rymanów Zdrój health resort, covering several towns, covers an area of 7 899 hectares. The beginnings of the Rymanów Zdrój health resort date back to 1876 when the first mineral springs were discovered. The founders of the spa are Anna and Stanisław Józef Potoccy, who were the owners of Rymanów. Rymanów Zdrój obtained the spa statute pursuant to the resolution of the Provincial National Council in Rzeszów in 1973. The current statute was granted in 2009 [5].

The mineral elements are the therapeutic agents most used in Rymanów Zdrój. The use of chloride-carbonate-sodium, bromide and iodide waters with the content of carbon dioxide is used here. In addition, mineralized forest mud with a small content of iodine and trace amount of sulphate is also used in medicine.



Diseases	Treatments
 diseases of the upper respiratory tract: chronic and recurrent inflammation of the throat, tonsils and larynx, inflammation of the paranasal sinuses, allergic diseases; lower respiratory tract diseases: recurrent bronchitis and bronchitis, bronchial asthma, chronic obstructive pulmonary disease, pulmonary emphysema, conditions after resection of lung tissue; cardiovascular diseases: ischemic heart disease, conditions after myocardial infarction, conditions after cardiac surgery, hypertension; motor organ diseases: degenerative spine disease, multiple locomotor dysfunctions following overload and degenerative changes, conditions after injuries, rheumatoid arthritis, cataracts, congenital deformity of the musculoskeletal system, scoliosis and postural defects; diseases of the urinary tract: chronic nephritis, urolithiasis, etc. 	 individual and collective inhalations; mud treatments; mineral, acid-carbon and pearl baths; Scottish shower; underwater massage, hydromassage, whirlpool massage; classic and pneumatic massages; therapies in the field of heat therapy (mud, paraffin, sauna; light therapy: solux lamp, quartz lamp; kinesitherapy: individual and collective exercises in the pool, nordicwalking; physical therapy: iontophoresis, ultrasounds, phonophoresis, laser, electrostimulation; drinking cures.

Tab. 2. Diseases treated in Rymanów Zdrój and treatments offered by sanatoriums

Source: own elaboration based on [7]

As part of the Rymanów Zdrój spa, there are about five sanatorium centers.

Polanczyk

Polańczyk Zdrój is a resort town of Solina, located at an altitude of about 400 m above sea level. on the narrow peninsula of Lake Solina on the outskirts of the Bieszczady Mountains. The Polańczyk Health Resort consists of: Polańczyk Zdrój, Panorama Estate, housing estate on Górce, Polańczyk and the Myczków parish. The spa covers an area of 1 4574 ha [5].

The healing factors that are used in the spa are mineral healing waters and climate. Among the sources found there are hydrogen-chloride-sodium, hydrogen-carbonate-chloride-sodium and hydro-carbon-chloride-bromide-iodine. The foothill climate prevailing in this area with the dominant features of the continental climate combined with the extremely picturesque surroundings is ideal for climate therapy [8]. In addition, the proximity of the Soliński Lagoon and the Bieszczady forests creates extremely favorable conditions for spending time and treatment. There are also cultural and entertainment attractions.



Гаb. 3.	Diseases	treated in	Polańczyk	Zdrój an	d treatments	offered by	v sanatoriums
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	Diseases	Treatments
•	respiratory diseases (inflammation, emphysema,	, • bath therapeutic baths;
	bronchial asthma, chronic pneumonia);	• hydrotherapy showers;
•	motor and rheumatic diseases (dysfunctions of the	• mouth and group inhalations;
	hip joints, posture defects, post-traumatic	• underwater and dry massages.
	conditions);	
•	diseases of the endocrine system and metabolism	1
	(diabetes, obesity);	
•	skin diseases;	
•	women's diseases.	

Source: own elaboration based on [9]

Horyniec Zdrój

Horyniec Zdrój is the only health resort in the lowland Podkarpacie region. The village is located in the Lubaczów poviat in the valley at the foot of Roztocze. Horyniec Zdrój municipality covers an area of 20 310 ha. The area included in the spa protection zones covers an area of 12 925 ha. The first documented mentions about Horyniec in the context of treatment date back to the end of the 19th century and concern the bathing establishment founded by Aleksander Franciszek Oskar Poniński. Horyniec obtained the title of the spa in 1976, and the current status was granted in 2009 [5].

The healing factors used in the Horyniec Zdrój health resort include sulfur-hydrogen, hydrogen-carbonate and calcium-sodium waters as well as mud deposits. In addition, the favorable condition for treatment is an extremely favorable climate.

As part of the Horyniec Zdrój health resort, there are three sanatoria which, using natural healing factors, accept patients. The table presents diseases treated in the spa and offered treatments.

	Diseases		Treatments		
•	respiratory system diseases;	•	drinking cures: crenotherapy;		
•	motor and rheumatic diseases;	•	baths: sulphide-hydrogen sulphide, carbonic acid,		
•	skin diseases; female diseases.		pearl-ozone baths, four-chamber bath, whirlpool bath		
	and legs; massages: underwater total_underwater multi-stream				
		•	massages: underwater total, underwater multi-stream;		
• Scottish shower;					
		•	mud and paraffin wraps;		
		• physical therapy: iontophoresis, magnetotherapy,			
			terapuls, ultrasounds, diadynamics, laser therapy;		
		• electro and phototherapy;			
		•	individual and group gymnastics.		

Tab. 4. Diseases treated in Horyniec Zdrój and treatments offered by sanatoriums

Source: own elaboration based on [10]



To sum up

The issue of the characteristics of spas in the Podkarpacie region, it is necessary to emphasize the important possibilities and the extensive health offer offered by spas located in this area. The functioning of such centers allows for effective help and offering an attractive spa stay for patients.

Methodology of research

The subject of this study is the present state and development opportunities of the Podkarpackie health resorts and the spa tourism taking place in their areas.

The aim of the work is to analyze spas in Iwonicz Zdrój and Rymanów Zdrój.

Then, the research problems identified by the authors were:

- 1. Is the condition of health resorts conducive to the development of spa tourism.
- 2. Is spa tourism more popular among young people or among older people?

In response to research problems, the authors used the diagnostic survey method. The survey tool was a questionnaire. The research technicians were a questionnaire that contained single or multiple choice questions and was completely anonymous.

It was carried out in centers located in Iwonicz Zdrój and Rymanów Zdrój. The questionnaires were filled out anonymously by spa employees. 100 questionnaires have been collected.

Findings

Fig. 1 shows the age of patients. The largest number in Iwonicz Zdrój are people between 51-60 years of age (63%), successively between 30-40 years (18%), then between 41-50 (15%) and between 21-30 (3 years old) %) and over 60 years (1%). In this spa, according to research, there is no person under 20 years of age. In Rymanów-Zdrój, the most patients are between 51-60 (49%) and up to 20 years of age (28%), then between 21-30 (9%), between 41-50 (7%), between 31-40 years (5%) and above 60 years (2%).





Fig. 2 shows the average time of stay of the patients. In Iwonicz Zdrój it was the most from 15-30 days (83%) from 8-14 days (16%) to 7 days (1%). It is similar in Rymanów Zdrój.







Fig. 2. Time of stay of the patients Source: own study

Fig. 3 shows the composition of tourist offers, which in Iwonicz Zdrój consist of tourist attractions (79%), transport (63%), admission tickets (41%), pilot care (8%). Whereas in Rymanów Zdrój they are, in turn, tourist attractions (82%), admission tickets (47%), transport (42%), pilot care (5%).



Fig. 3 . Composition of spa tourist offers

Source: own study

Fig. 4 concerns the use of spa tourism offers. In Iwonicz Zdrój, 81% opt for tourist services, and 19% of patients do not show interest. In Rymanów Zdrój, it looks the same because participation in spa tourism takes 74%, and not 26% of patients decide.





Fig. 4 . Using spa tourist offers Source: own study

Fig. 5 shows the advantages of the health resort in Iwonicz Zdrój, which are successively attractive treatments (87%) treatment and rest (58%), a wonderful microclimate (35%). Similarly, in Rymanów Zdrój, it is attractive treatments (92%), treatment and rest (64%), a wonderful microclimate (32%).



Source: own study

Conclusion

Spa tourism is an opportunity for the development and promotion of the Podkarpackie Voivodeship, and consequently requires constant, thorough studies of the condition of the spa base and the tourist movement taking place there, but also in the context of its development and broadening the range and range of activities.

Based on the tests carried out, it can be concluded that:

Tourist traffic in the studied spas is generated at a high level.

1. The time of stay of patients in the spas studied is approximate and ranges from 15-30 days.



2. Spa tourism is more popular among people between 51-60, because these people are the most in the spa.

The condition of health resorts is conducive to the development of spa tourism.

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EVALUATION OF IMPLANT SURFACE POROSITY USING IT TOOLS

Żaneta Garczyk*, Sebastian Stach, Zygmunt Wróbel

Department of Computer Biomedical Systems, Faculty of Computer Science and Materials Science, University of Silesia in Katowice * corresponding author: zaneta.garczyk@us.edu.pl

Abstract:

The main objective of the study was to develop, using IT tools, a method for assessing open pore geometry of a biomaterial surface, which would enable to determine its porosity degree. Measurements with the LEXT OLS4000 confocal laser scanning microscope were made in order to obtain confocal microphotographs of several areas of a biomaterial surface. The research material was a coating of aluminium oxide, which is widely used in implants and drug carriers. Image analysis was carried out using the Mountains Surf software from Digital Surf and the SPIP software from Image Metrology. An image processing method was developed, which enabled to segment even interconnected pores. Then the parameters characterizing surface pores were determined and surface porosity was calculated.

Keywords:

surface porosity; pore geometry; image processing; SPIP; MountainsMap

Introduction

Porous materials are materials that have a large number of empty spaces inside, which are called pores. A solid constituting the matrix of a porous body is called a skeleton or carrier. Material porosity is a property of solids determining the size and number of pores occurring inside the material and describing their distribution in the examined space. There is surface porosity and volume porosity. The surface porosity is defined as the ratio of the pore surface area in a given cross section to the total cross-sectional area. The volume porosity, on the other hand, is determined as the ratio of the volume occupied by pores to the total material volume. Porosity is a dimensionless parameter, given as a percentage [1-4].

The use of metal implants covered with layers of porous bioceramics is of great importance in medicine. Implants, in whole or in part, are made of metal alloys due to the good mechanical properties of this group of biomaterials [5]. The applied bioceramic coating leads to the creation of implants combining satisfactory mechanical properties with an improved interface between the implant and tissues. The porous surface of prostheses affects the rate and quality of the osseointegration process. The appropriate size of pores and connections between the pores determines a good and lasting connection of the implant with the tissue by its growing into the



biomaterial pores [1, 6-8]. In addition, porous biomaterials are ideal as drug carriers, because they allow for the placement of a therapeutic substance with antibacterial and antiseptic action on the prosthesis surface, and then the introduction of the drug directly into the human body during implantation. An implant with an incorporated drug allows to avoid post-operative complications and prevents the formation of inflammation, while reducing the disadvantages of systemic treatment, which reduces the time and cost of treatment, and thus improves the patient's comfort. This type of therapy is called targeted therapy. Materials with a porous structure must meet strict requirements for open and total porosity as well as the size and shape of pores. The control of structural parameters directly allows to control the amount of the drug that can be placed in the open pores of biomaterials and delivered to the body along with the implant [9-12].

Different techniques for determining porosity are used in the characterization of biomaterials. However, there are a number of problems faced by scientists studying surfaces. Most often they are difficult to access or very sensitive. Then, non-invasive microscopic techniques, which allow for the observation of surface pores, are an alternative. Two-dimensional images obtained with the use of a microscope are subjected to computer analysis, which allows to determine the parameters characterizing pores [13].

The main objective of the research is to develop, using IT tools, a method for assessing open pore geometry of a biomaterial surface, which would allow to determine its porosity degree. The developed method will use the analysis of surface images obtained with the use of confocal laser microscopy. It will be a non-destructive method, which means that samples after the test will be suitable for further applications. The method will not require special preparation of biomaterials for testing, and the results will be obtained practically immediately. The developed technique will be universal, so it will be possible to use it for various materials used in implantology.

Material and research method

Research material

The research material was a sample of an aluminium alloy coated with a thin layer of aluminium oxide (Al₂O₃), which is now widely used in implants and drug carriers [14-16]. The surface of the tested aluminium oxide was created by hard anodizing at 20°C, at a constant anode current density of 4 A/dm² and electric charge density of 240 Amin/dm². The analysed sample was disc-shaped with a diameter of 65 mm and thickness of about 5 mm.

Measuring tool

In order to obtain confocal microphotographs of several areas of the porous biomaterial surface, measurements were made using the LEXT OLS4000 confocal laser scanning microscope. 15 surface fragments were chosen for which images were acquired at 25-, 50- and 100-fold magnification. This procedure allowed to choose the magnification at which pores were still clearly recognizable and sufficiently numerous in the field of view. Finally, the tests were done with a 50x magnification lens. The dimensions of the analysed surfaces were 259x259 μ m.

The microscope has a UV laser and uses confocal scanning technology, which, in contrast to wide-field technology, provides a very high resolution. The system scans the sample point by point.



Signals are detected using a photomultiplier, in front of which there is a confocal shutter that excludes from the image the rays of light reflected from the surface and coming from outside the plane of sharpness. The intensity of light is measured at each point by the photomultiplier, the intensity map is obtained as a result of the movement of the lens in the Z axis, which is precisely controlled thanks to the use of a linear system with an increment of 1 nm. Based on the intensity map, a three-dimensional surface image is reconstructed [17].

Software

The acquired material surface images were analysed by means of the MountainsMap® Premium software from Digital Surf and the SPIP® software from Image Metrology, which are intended for the processing and analysis of microscopic images.

Research method

First, the images were analysed using MountainsMap® Premium. In the first step, the image layer (Fig. 1a), the intensity layer (Fig. 1b) and the topography layer (Fig. 1c) were isolated from the initial image. The topography layer was pre-processed, which involved surface levelling by means of the second-order polynomial approximation as well as surface waviness filtering by using a Gaussian filter. Then, binarization was performed. The binarization threshold was set automatically, which deprived the analysis of subjectivity. The next operations were morphological closing and grain sorting, which consisted in setting a threshold below which the pores were treated as noise and were removed from the image (Fig. 1d).



Fig. 1. Image analysis in the MountainsMap software: a) image layer, b) intensity layer, c) topography layer, d) resultant image Source: authors' own analysis



A parallel analysis was carried out using the SPIP software. In the first step, the image layer (Fig. 2a), the intensity layer (Fig. 2b) and the topography layer (Fig. 2c) were isolated from the initial image. The topography layer was pre-processed, which involved surface levelling by means of the second-order polynomial approximation as well as surface waviness filtering by using a Gaussian filter.



Fig. 2. Image analysis in the SPIP software: a) image layer, b) intensity layer, c) topography layer Source: authors' own analysis

The next step was the detection of surface pores using the SPIP pore and particle analysis module. The module allows for detection using 4 different detection methods, based on thresholding, watershed segmentation and circle detection. Each of the detection methods was used in the study in order to extract the biomaterial surface pores. At the same time, the noise attenuation in the image was set, the pores cut by the image frame were excluded and the interconnected pores were separated by finding a narrowing. The first of the detection methods used was thresholding with an automatically calculated threshold value (Fig. 3a). The second method was circle detection



(Fig. 3b). Next, watershed segmentation (Fig. 3c) and watershed segmentation with a gradient image (Fig. 3d) were applied.



Fig. 3. Image analysis in the SPIP software – the resultant image obtained using the detection methods: a) thresholding with an automatically calculated threshold value, b) circle detection, c) watershed segmentation, d) watershed segmentation with a gradient image Source: authors' own analysis

Analysis of results

When analysing the resulting image obtained using MountainsMap® Premium (Fig. 1d), it can be concluded that the applied software and analysis were unable to provide satisfactory results because they did not allow for the separation of interconnected pores.

However, the comparison of the resulting images obtained using the four detection methods available in the SPIP software (Fig. 3) showed that thresholding with an automatically determined threshold value did not detect all the pores present on the material surface. In addition, this method



is not able to divide interconnected pores. Circle detection is a method of detecting regular shapes in the image. In this case the method is not applicable, because in reality the pores are only similar in shape to the circle. The watershed segmentation method is applicable when the image is completely covered with adjacent pores with no gaps between them. The best results were therefore obtained using watershed segmentation with a gradient image.

The resulting images obtained using the SPIP software and watershed segmentation with a gradient image were subjected to further analysis. The software allows to perform precise measurements of pore geometry, as a result of which parameters characterizing the surface pores are generated. The number of pores per unit plane (N_A) was determined, i.e. the ratio of the determined number of pores to the analysed area. The values of parameters characterizing the segmented pores were also generated - mean diameter (\overline{D}), mean circumference (\overline{O}), mean surface area (\overline{A}), as well as the total surface area occupied by all pores designated on the surface of the examined area (A_{sum}). Then, for each area, surface porosity (P) was determined as the ratio of the total surface area occupied by the pores to the analysed area (1) (Tab. 1).

$$P = \frac{A_{sum}}{A_{area}} \tag{1}$$

where:

P – surface porosity;

 A_{sum} – total pore surface area [μ m²];

 A_{area} – analysed surface area [μ m²].

Area	$N_A[1/\mu m^2]$	<u></u> D _[μm]	<u></u> [μm]	\overline{A} [µm ²]	A _{sum} [μm ²]	Р
1	0.0075	4.38	16.11	17.11	8641	0.13
2	0.0072	4.57	16.85	19.29	9377	0.14
3	0.0076	4.33	15.93	16.85	8625	0.13
4	0.0102	4.10	15.11	15.65	10657	0.16
5	0.0089	4.25	15.60	16.23	9722	0.15
6	0.0098	4.29	15.76	16.78	11041	0.17
7	0.0088	4.33	15.91	17.15	10100	0.15
8	0.0076	4.17	15.23	15.59	7934	0.12
9	0.0072	4.27	15.57	16.21	7779	0.12
10	0.0089	4.16	15.26	15.86	9518	0.15
11	0.0088	4.35	15.95	17.02	10077	0.15
12	0.0083	4.02	14.66	14.47	8071	0.12
13	0.0085	4.22	15.60	16.24	9289	0.14
14	0.0089	4.32	15.91	17.02	10129	0.15
15	0.0085	4.21	15.44	16.26	9217	0.01
average value	0.0085	4.26	15.66	16.52	9345	0.13

Tab. 1. Morphological parameters of the analysed fragments of the porous biomaterial surface obtained using the SPIP software

Source: authors' own calculations

The obtained values of parameters (Tab. 1) show geometric differentiation of the surface. The number of pores on the unit plane ranges from 0.0072 (areas 2 and 9) to 0.0102 (area 4). The



average pore diameter ranges from 4.02 μ m (area 12) to 4.57 μ m (area 2). The smallest mean value of the pore circumference on the cross section was 14.66 μ m (area 12), whereas the largest was 16.85 μ m (area 2). The smallest mean surface area of 14.47 μ m² is characteristic of area 12 and the largest of 19.29 μ m2 is characteristic of area 2. The total surface area occupied by the pores ranges from 7779 μ m2 (area 8) to 11041 μ m2 (area 6). Surface porosity varied in different areas of the tested biomaterial surface layer. The highest porosity was 0.17 (area 6) and the lowest was 0.01 area 15). A relationship was observed between the number of pores and the total surface area occupied by the pores as well as surface porosity. The largest surface porosity is characteristic of areas with a large number of pores and a large surface area of these pores.

Conclusions

The main goal of the research was to develop, using IT tools, the method for evaluating open pore geometry of a biomaterial surface, which would allow to determine its porosity degree. The developed method is based on the analysis of the surface image acquired using confocal laser microscopy.

The research material was an aluminium oxide coating (Al₂O₃), which was produced by hard anodizing. The microscopic images of the sample, acquired with the LEX OLS4000 confocal laser scanning microscope, were analysed using the MountainsMap® Premium and SPIP® software. Next, an image processing method was developed that allowed to isolate the pores while eliminating as many defects and disturbances as possible.

In the first stage, the image was processed using the MountainsMap® Premium software. However, the applied analysis method did not provide satisfactory results. The images were then analysed in the SPIP software. First, it was necessary to extract layers from the initial image. The separated topography layer was then pre-processed. In order to segment the surface pores, 4 detection methods available in the program were used. In the next step, the noise in the images was removed and the pores cut by the image frame were excluded. The last operation was to separate interconnected pores. The resulting images obtained using each of the detection methods available in the program. The best method for detecting biomaterial surface pores was watershed segmentation with a gradient image. The SPIP software also performed precise measurements of pore geometry, which enabled to determine the porosity degree of the porous bioceramic surface. When comparing the obtained results, it can be stated that the material tested has geometric surface variability. The developed method can be used in practice for image processing and analysis to assess the porosity degree of a porous biomaterial surface.

General comments

The scientific work was financed from budgetary funds for science in the years 2016-2020, as a research project under the "Diamond Grant" program.



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MECHANICAL DESIGN OF AN ELECTRIC MOTORCYCLE'S REAR AXLE

Kacper Leszczyński1*, Wojciech Pawlak2

¹ Department of Maintenance and Operation of Logistics, Transportation and Hydraulic Systems, Faculty of Mechanical Engineering, Wrocław University of Science and Technology, Wrocław
² Department of Fundamentals of Machine Design and Tribology, Faculty of Mechanical Engineering,

Wrocław University of Science and Technology, Wrocław

* corresponding author: kacper.leszczynski@pwr.edu.pl

Abstract:

Electric vehicles are constantly growing in popularity, therefore there is need to design new parts and joints for building unique vehicles and adapting electric drives to solutions known from conventional vehicles. Article presents the idea of joint of standard motorcycle wheel and unique swingarm designed to Light Electric Motorcycle Thunder. Rear wheel axle made by students from Wrocław University of Science and Technology proved its strength during difficult rides at competitions. Moreover, special chain tensioner, made for mentioned motorcycle was described in the paper. It connects rear wheel axle to the swingarm and allows to maintain the right chain tension.

Kewords:

motorcycle, chain, swingarm, axle, chain tensioner

Introduction

Creating of innovative vehicle is related to the need to develop unique parts and joints. This article presents mechanical design of a rear axle and chain tensioner of Light Electric Motorcycle Thunder which was entirely designed and made by students of research group PiRM of Wrocław University of Science and Technology.

Light Electric Motorcycle

LEM (Light Electric Motorcycle) is a students' project created by research group PiRM of University of Science and Technology in Wrocław. This project relies in building motorcycles which complie with regulations of SmartMoto Challenge student's competition. The theme of 2018 contest was Dakar electric motorcycle. The vehicle built to participate in this competition is called LEM Thunder [1]. Main parameters of mentioned motorcycle can be seen in Tab. 1.

In 2018, students from PiRM organized electric motorcycle competition at their university campus called Wrocław SmartMoto Challenge. LEM Thunder turned to be a winner, ahead of other teams from Poland and Russia. Fig. 1 shows described motorcycle during its rides in competition.



Mass [kg]	120
Power [kW]	30
Continuous torque [Nm]	290
Max velocity [km/h]	120
Front wheel size	2,15x21
Rear wheel size	1,60x18

Гаb. 1. Main	parameters	of LEM	Thunder	[1]
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Source: LEM Thunder Design Brief



Fig. 1. LEM Thunder Source: LEM Wrocław (Paweł Rogalski photo)

Wheel axle

LEM Thunder is one of its kind. It has unique rear suspension, including own design swingarm, for this reason it was necessary to design wheel axle. Dimensions of an axle was defined by:

- hub hole diameter,
- swingarm width,
- wheel and hub width.

Model and drawing of LEM Thunder's rear axle designed by students from research group PiRM are shown in Fig. 2 and 3.





Fig. 3. Rear axle – drawing Source: own source

Value of the diameter and dimensional tolerance were chosen for hub bearing. The exact value is to ensure appropriate working conditions. During driving, when the wheel with the hub rotates, the axle should be motionless in relation to the swingarm. These conditions are provided by the flange, which is placed at one end. The flange fulfil one more task, does not allow axle to move along. External thread was made for the nut that holds axle to swingarm and completely fixes it. Two threaded holes are used to attach crash pads that protect the motorcycle in the event of the fall. They are also made by students of research group PiRM.

The axle is made of 20MnCr5 steel, because of its high strength as well as susceptibility to the carburizing process. Carburised top layer is characterized by high hardness of up to 64 HRC, which makes it highly resistant to abrasion. In combination with Yeld strength at the level 830 MPa gives a very good material for this application [2].

Before making an element it is necessary to check its strength. Finite element method (FEM) was used for this. Fig. 4 and 5 show results of static analysis for the case in which the forces acting on the axle were the biggest.





Fig. 4. Stress fields Source: own source



Fig. 5. Displacement fields Source: own source

FEM analysis have shown that even in the worst load case maximum stress was 110 MPa. This is much lower value than Yeld strength. In addition, maximum displacement amounted to 0,01 mm. Such a big difference between the maximum value of stress and Yeld strength should be reduced by optimizing the geometry and dimensions of axle. This should be taken care of in the next construction of the Light Electric Motorcycle.

Chain tensioner

Vehicle with chain drive are always equipped with various types of tensioners. Correct chain tension is very important especially in high-speed drives like a motorcycle drive. When the chain is too loose there is the possibility of its falling and damage to the vehicle. It also gets quicker wear [3]. Whereas the chain is too tight there is a danger of breaking it and both sprockets. In addition, the chain is stretched during use, so it is necessary to control its tension and correct it. To sum up,



chain tensioners guarantee appropriate chain tension at all times, thus minimizing maintenance and wear.

Chain tensioner designed by students of research group PiRM is shown in Fig. 6 and 7. It consists of :

- 1. swingarm,
- 2. two inserts welded to swingarm,
- 3. two sliders with threaded rods,
- 4. two wheel positioning nuts,
- 5. axle nut,
- 6. wheel axle,
- 7. nut lock.



Fig. 6. Chain tensioner assembly Source: own source





Fig. 7. Cross-section through the chain tensioner assembly Source: own source

To set the appropriate chain tension, first, loosen the axle nut, next turn both wheel positioning nuts until the correct tension is obtained, than tighten the axle nut. It is important that both sliders are equally extended because than the axle will be perpendicular to the driving direction.

Described method of obtaining tension is manual, therefore it should be repeated from time to time, depending on the dynamics of driving style. In addition, it is not a very accurate method, there is possibility of obtaining a non-centralized wheel. However, this is a very simple and reliable method, which is why it was used in an off-road motorcycle.

Summary

The process of creating parts for unique vehicles requires several things to be considered. There is need to think about connecting to other parts, movement and how to realize it, static or dynamic strength, fatigue strength and a lot more. Due to the results obtained, it can be concluded that described process of creating the motorcycle parts is correct. In Fig. 8 there can be see actual view of described axle and chain tension mounted on an electric motorcycle LEM Thunder. It covered many kilometers in difficult off-road conditions, but designed components do not wear signs of wear.




Fig. 8. Actual view of rear wheel axle and chain tensioner mounted on motorcycle Source: own source

Rear wheel axle is very simple to make, moreover it fulfils all the assumptions of the project. It has the right dimensions, strength and top layer conditions, also has holes for crash pads. The only significant disadvantage of the designed axle is its unoptimized strength, which increases the mass. This defect does not adversely affect its operation. However, in future constructions, the process should be improved.

Chain tensioner described in the above article is also very simple and reliable, in addition, it works great in such constructions as off-road motorcycles. The applied solution does not involve any risk loosening the chain during fast driving on uneven terrain.

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THE ULTRASOUND ASSESSMENT OF THYROID DISEASES IN PEDIATRIC POPULATION

Małgorzata Matuszek¹, Ewa Kopyto¹, Michał Kaczor¹, Magdalena Maria Woźniak²

¹ Students of Scientific Society at Department of Pediatric Radiology, Medical University of Lublin ² Department of Pediatric Radiology, Medical University of Lublin * corresponding author: ewa.kopyto@gmail.com

Abstract:

The assessment of the thyroid abnormalities in children with ultrasonography (US). 100 consecutive patients were examined in the Department of Pediatric Radiology, Medical University of Lublin, between November 2018 and February 2019, using Philips EPIQ 5G and Siemens Acuson S3000 ultrasound scanners with linear transducers 8-14 MHz. The group included 56 girls and 44 boys at the age 2-18, referred due to primary thyroid disease (n=48) or other health problems (n=52). Echogenicity, presence of focal lesions, fibrotic changes, vascularity, contours and total volume of the gland were evaluated. US showed abnormal echogenicity in 28 patients, 29 presented focal lesions, 4 irregular contours, 6 fibrotic changes and 29 had abnormal vascularity. Ultrasonography is proven diagnostic tool which is helpful to complete the whole process of thyroid dysfunction diagnosis.

Keywords:

thyroid dysfunction, children, Hashimoto thyroiditis, ultrasonography

Introduction

Disorders affecting the thyroid gland represent the most common endocrinopathies in childhood [1]. It is commonly known that thyroid disease is a frequent and serious problem in adults, that concerns 22% of the general population at different age [2, 3]. Thyroid diseases are the most common in population at the age between 50 and 59 and next at the age of 40-49. The research shows that women are more likely to develop thyroid disease. Statistics indicate that female sex suffers about 8.5 times more often [3]. Nevertheless this issue also occurs in pediatric population. Thyroid hormones influence many processes in child development, thus the diagnosis of thyroid disease in childhood is Hashimoto thyroiditis (HT) [4]. HT is relatively common disease, whose prevalence in childhood has been reported to range around 3% and to reach its peak during adolescence [5]. At the time of diagnosis children and adolescents with HT may remain asymptomatic [4]. One of the studies shows that euthyreosis occurs in 52.1% of children with HT [4, 5].



Thyroid disease can be divided into two main groups taking into account the hormonal activity of the thyroid gland; (1) hypothyroidism and (2) hyperthyroidism which differ from the normal secretory function of the gland called euthyreosis. It is estimated that about 2% of population suffer from hypothyroidism. The incidence increases with the age of patient and 2-4% of elderly population has this diagnosis [3]. Hypothyroidism in children can be classified as primary or secondary and can be either congenital or acquired, transient or permanent. The incidence of congenital hypothyroidism varies depending on geographical location and seems to occur more often in girls than in boys [1]. About 85% of congenital hypothyroidism appears to be sporadic and 15% is autosomal recessive in inheritance [2, 3]. Overt hypothyroidism is second most frequent thyroid function pattern in HT presentation, it occurs in 22.2% of children [5]. This disease may be caused also by surgical damage of thyroid gland, conditions after radioactive iodine treatment or after complete thyreoidectomy [3]. Hyperthyroidism concerns about 1-1.5% of population. American data show that hyperthyroidism concerns 20 times more frequent pediatric than adult population [3], but only 1-5% of them begins before the age of 16 [1]. Another study shows that females suffer from hyperthyroidism 4 times more often than males [2]. It was found that there are family predispositions for hyperthyroidism to occur [3]. The most frequent form is Graves disease, more rarely occur: autoimmune thyroiditis, nodular goiter and thyroid adenoma. Graves disease accounts for at least 95% of cases of hyperthyroidism in children and it occurs more frequently in females than i males, in a ratio of 3:1 to 5:1 [1].

When evaluating the possibility of thyroid dysfunction it is important to assess all symptoms, blood tests and thyroid imagining. The ultrasonography (US) is primary imaging modality for evaluating thyroid diseases. Thyroid gland is a superficial structure that can be imaged with high-frequency linear array transducers [6]. US enables the assessment of shape and size of thyroid gland, measuring width, length and depth, echotexture, focal lesions and its vascularity [2]. The normal thyroid parenchyma has homogenous medium- to high-level echogenicity, which makes detection of focal cystic or hypoechoic lesions relatively easy. Many of the diseases and imaging findings in children are similar to those seen in adults [6]. In Hashimoto thyroiditis US is useful for measuring thyroid size and assessing echotexture. The gland is enlarged with a diffusely heterogenous, coarsened echo appearance. There are multiple hypoechogenic nodules or areas. In Color Doppler imaging the vascularity is normal to decreased. In hyperthyroidism such as Graves disease radiological image of the thyroid gland is enlarged, heterogenous and diffusely hypoechoic. With Color Doppler there is a hypervascular pattern referred to as "thyroid inferno" [7]. The patient is examined in the supine position.

Material and methods

The study included 100 consequtive patients referred for the ultrasound examination by Department of Pediatric Endocrinology and Diabetology (35), Endocrinology Outpatient Clinic (29), Department of Pediatric Hematology, Oncology and Pediatric Transplantology (29), Diabethology Outpatient Clinic (3), Department of Pediatric Gastroenterology (2), Department of Pediatric Cardiology (2), within a period from November 2018 to February 2019. All patients were examined in Department of Pediatric Radiology, of Medical University of Lublin. Children from the study



group were at the age from 2 to 18 years, including 56 girls in average age 12.8 years and 44 boys in average age of 11.3 years. The overall study population was divided into two main groups, according to the cause of referral for the ultrasound scan, which where: (1) patients referred due to primary thyroid disease; (2) patients referred due to other, non-thyroid case who underwent the US scan as thyroid screening. The first group included children with hyperthyroidism or hypothyroidism during the diagnosis or treatment. The second group included children with acute myeloid leukemia (14), hypopituitarism (6), immunodeficiency syndrome (5), obesity (4), diabetes (4) and other (11), who have had an ultrasound as an additional control test.

The examinations were carried out using Philips EPIQ 5G and Siemens Acuson S3000 ultrasound scanners with linear array transducers of the frequency of 8-14 MHz. High frequency transducers are destined to examine superficially located structures such as the thyroid gland. All children were examined using the same technique and equipment (with different US transducer frequency). Children were examined in the supine position with the neck tilted back. The whole gland; both lobes and isthmus, and submandibular lymph nodes were assessed. Ultrasound images showed the thyroid in the frontal and sagittal planes.

During the study there were 6 key features assessed; (1) echogenicity and structure of the gland, (2) presence of focal lesions and its sizes, (3) vascularity, (4) presence of fibrotic changes, (5) contours and (6) total volume of the gland. The volume of each lobe was counted separately with automatic algorithms installed in the software of the US scanner derived from 3 dimensions and then summed up..

After conducting all the scans, obtained results were collected and divided into particular categories. Characteristic features were extracted in the ultrasound image. There was correlation established between the incidence of changes in the thyroid gland and the occurring thyroid disease. In addition, obtained ultrasound thyroid image was compared to a typical thyroid image for a given thyroid pathology.

Results

More than a half of the examined patients (n=52) suffered from a different disorder than thyroid disease. Among them, the most common were bone marrow diseases: acute lymphoblastic leukemia (ALL) (n=9) and acute myeloid leukemia (AML) (n=3). In radiological image 39 patients showed no changes in the thyroid gland without noticeable advantage of gender (female n=20, male n=19). Summary of general changes in the thyroid gland are presented in Tab. 1., without disease consideration.



The Book of Articles National Scientific Conference "Science and Young Researchers" III edition June 15, 2019, Łódź

Feature	Amount
Abnormal echogenicity	28
Focal lesions	29
Contours	4
Fibrotic changes	6
Vascularity	29
Enlarged volume	17

Tab. 1. Changes in the thyroid g	land
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Source: own study

In the ultrasound assessment, the total volume of the gland was estimated and was averagely about 9 ml, without consideration of the age. The mean thyroid volume for given age ranges is shown in Fig. 1. There has been noted the correlation between thyroid total volume and gender. Female total thyroid volume was on average 10.5 ml, while in male on average 7.1 ml.



Fig. 1. Average thyroid volume in children Source: own study

48 of the examined patients suffered from primary thyroid disease. The most frequent disorder was hypothyroidism (n=28) including 17 females and 11 males. The most common form of hypothyroidism and at the same time the most common pathology among all was non-autoimmune hypothyroidism which occurred in 20 patients (71.4% of all patients with hypothyroidism), while autoimmune thyroiditis occurred in 8 patients, which accounts for 28.6% of all patients with hypothyroidism. Autoimmune thyroiditis concerned 87.5% of female, which indicates female dominance. In ultrasound images of hypothyroidism incorrect echogenicity occurred in 11 patients, focal lesions in 8, uneven contours in 3, fibrotic changes in 4 and abnormal vascularity in 13 patients.



Hyperthyroidism was the second most common disease and it was diagnosed in 9 patients (9%). Two forms of this pathology were identified: Graves disease and toxic nodular goiter. Graves disease occurred only in 2 patients per 100 tested. Whereas toxic nodular goiter occurred in 7 patients. Without clear gender domination. In ultrasound images of hyperthyroidism 6 of all presented incorrect echogenicity, 4 presented focal lesions, none presented uneven contours, fibrotic changes occurred in 1 case, 6 presented abnormal vascularity.

Discussion

Hypothyroidism seems to be a serious clinical issue in children. Thyroid hormones play significant role in correct development of the nervous system, in metabolism regulation, and are biochemical regulators of many organ functions [8]. Unfortunately, thyroid insufficiency incidence is documented to be very common thyroid disorder, which average frequency is 1:3,300 for Europe [9]. According to our results, the vast majority of causes of hypothyroidism are other causes than autoimmune inflammation (69%). Their prevalence rates in children have been reported as being 1:4,000 for thyroid dysgenesis, 1:30,000 for thyroid dyshormonogenesis, 1:40,000 for transient hypothyroidism, 1:100,000 for central hypothyroidism [10, 17]. However, Koch et al. emphasizes that the main cause of hypothyroidism worldwide is iodine deficiency and second ranks chronic autoimmune thyroiditis, and our study confirm that [11].

Statistics show that Hashimoto thyroiditis frequency in childhood diseases in general ranges around 3% [10, 12]. At the same time it is one of the most common causes of acquired hypothyroidism that affects 1.3% of children and it occurs more frequently in females than in males in ratio of 4–7:1 [12, 13]. On the other side, in article of Takashi Akamizu, et al. one can find the of the incidence of Hashimoto's thyroiditis is unknown but is roughly equal to that of Graves' disease and ranges 0.3 - 1.5 cases per 1,000 population per year [12, 14]. According to our study HT occurred in 8% of the whole study group and was the cause of hypothyroidism in 28.6%. There was significant female dominance observed in the ratio of 7:1. At the same time, other forms of hypothyroidism were the most common disease in our study group. Contrary to the results of Wasniewska M. et al., who claim that HT is the most common disease [4].

On sonography, according to Solbiati L. et al. HT is characterized by enlargement of the gland with diffusely heterogeneous echogenicity and multiple discrete hypoechogenic micronodule from 1 mm to 6 mm in diameter. There may be coarse septations from fibrous bands [14]. On Doppler imaging, the vascularity is normal to decreased [6]. In our study thyroid gland was enlarged because average volume of HT was 13.8 ml in comparison to average volume in the entire examined population which was 9 ml. On sonography, (Fig. 2.) most of the images of HT presented diffuse heterogeneous echogenicity (4). In 3 cases there were multiple hypoechogenic nodules in diameters 2-9 mm. Fibrotic changes occurred in 3 patients. In Color Doppler study (Fig. 3.) it was found that decreased vascularity of thyroid parenchyma outweighs the normal and occurs in 62.5%.





Fig. 2. Female patient, 18 years old with diagnosed HT. Ultrasound scan in B-mode revealed heterogeneous echogenicity of thyroid gland with presence of diffuse non demarcated hypoechogenic areas (white arrows) and presence of fibrotic changes (yellow arrows).

Source: own study



Fig. 3. CD-mode showed moderate hypervascularity of the whole gland. Source: own study

In 45% of nonautoimmune hypothyroidism patients (9 cases) there were no changes in ultrasound assessment detected. Other images was non-specific and highly comparable to the Hashimoto inflammation images. On sonography most of images presented diffuse heterogenous echogenicity (3), multiple hypoechogenic nodules (5) and fibrotic changes occurred in 1 patient. However, in Color Doppler study a significant part (70%) revealed normal vascularity.

Hyperthyroidism is defined as any condition of the thyroid gland that results in overproduction of thyroid hormones. It is relatively uncommon in children, however it can have significant impact on development if not diagnosed early. According to Koch hyperfunction of thyroid gland or



thyrotoxicosis is less common in children than hypothyroidism. In our study hypothyroidism and hyperthyroidism occurred in a ratio 29:9 [11]. Hyperthyroidism can occur in neonates but the majority of cases in pediatric population are in older children. Many studies report that the most common form of hyperthyroidism is Graves disease [1, 2, 14, 15, 17]. Whereas in our study toxic nodular goitre occurred to be the most common one, what is consistent with Elizabeth N Pearce's statement. Toxic nodular goitre is most common in regions where dietary iodine is sufficient [9]. In our study Graves disease occurred in patients in the age of 14 and 15. Our result is consistent with other study, which shows that the peak incidence is 11-15 years of age [6]. Graves disease may occur at any time during childhood, its frequency increases with age, peaking during adolescence. Only 1-5% of hyperthyroidism begins before the age of 16 [1, 15]. Another comparison may concern the gender of patients. Both of our patients with Graves disease were female, which agrees with Diane S. Babcock, who says there is a 5:1 female-to-male ratio [9].

Ultrasonographic image of Graves disease showed thyroid gland with diffuse heterogeneous echogenicity without focal lesions, with increased vascularity on Color Doppler. One of two our patients with Graves disease had the thyroid gland significantly enlarged. Our result are consistent with other studies, where radiological image of thyroid is symmetrically enlarged, heterogeneous and diffusely hypoechoic. With Doppler, there is hypervascular pattern referred to as "thyroid inferno" [6, 9, 14, 17]. In our study toxic goitre occurred in thyroid gland with heterogeneous, increased echogenicity, increased or slightly increased vascularity. Normoechogenic nodules occurred in some cases, as well as fibrotic changes. In some cases thyroid gland was enlarged. This image is comparable to many studies. According to Diane S. Babcock the gland is enlarged and heterogeneous, with multiple micro- and macronodule formation [6].

Ultrasonography may be helpful in differentiating between Graves disease, which is diffused and toxic multinodular goitre, where focal areas occur [9].



Fig. 4. Female patient, 14 years old with diagnosed GB. Ultrasound scan in B-mode revealed heterogenous echogenicity of thyroid gland with presence of diffuse non demarcated hypoechogenic areas (white arrows). Source: own study





Fig. 5. CD-mode showed severe hypervascularity of the whole gland. Source: own study

Although in our study nodular changes occurred in 17 cases of all thyroid diseases (35.4%), none of them showed malignancy features. And this is confirmed by Miller R.W. et al. who claims that thyroid carcinomas in childhood are rare, accounting for 1.5% of all tumors before the age of 15. At the same time Avula et. al reported that the risk of malignant thyroid nodules (papillary, follicular, and medullary) in children ranges from 14% to 40%, which is much higher than that of adults (9–15%) [16, 17].

Conclusion

Thyroid dysfunction diagnosis in pediatric population is a significant issue, because thyroid hormones affect child development. However, it has multiple etiologies, various clinical manifestations, and different potential therapies. Accurate treatment requires an appropriate diagnosis. Ultrasonography represents a sensitive diagnostic tool to examine the thyroid gland even in infancy.

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TRIBOLOGICAL PROPERTIES OF OIL CONTAINING GRAPHENE OXIDE OR HEXAGONAL BORON NITRIDE

Patrycja Nogas

Military University of Technology, Faculty of Mechanical Engineering, 00-908 Warsaw, ul. gen. Sylwestra Kaliskiego 2 corresponding author: patrycja.nogas@wat.edu.pl

Abstract:

The aim of this publication is to present the results of studies on the SN-650 oil base with various concentrations of graphene oxide (GO), reduced graphene oxide (rGO) produced by the Institute of Electronic Materials Technology in Warsaw and hexagonal boron nitride (h-BN) produced according to technology developed at Military University of Technology. Basic information about graphene and the possibilities of its application, in particular in the field of tribology, are presented. The second part of the publication presents the results of tests of tribological properties of samples with the addition of 0.05%, 0.1%, 0.5%, 1% and 2% of graphene oxide, reduced graphene oxide or hexagonal boron nitride. The measurements were carried out using the UNMT universal nano/microtester tester. The results obtained have shown the beneficial effect of adding additives in the form of graphene oxide or hexagonal boron nitride to the oil tribological properties to the SN-650 oil base.

Keywords:

graphene, hexagonal boron nitride, tribology

Introduction

In the context of tribological suitability and the potential use of lubricating oils, one of the main evaluation criteria is the examination and comparison of lubricity properties. The frictional nodes require the use of lubricants that will guarantee the creation of a durable boundary layer protecting against wear, with low frictional resistances. From the point of view of the operation of various tribological nodes, this durability is extremely important and determined by the lubricity properties of the oil, e.g. anti-wear properties.

In order to improve these properties, surface-active lubricity additives are used to generate a lubricating film adsorbed on friction surfaces. Among the many proposed compounds as limiting lubricity additives for oils, only a small number of them have found practical applications. Attempts were also made to use hexagonal boron nitride as an additive to improve the lubricity properties of the oil [1].



Due to the growing interest in graphene, as demonstrated by the literature analysis carried out, this paper presents the results obtained in comparative studies on the use of graphene oxide (GO) and hexagonal boron nitride (h-BN) as additives to the SN-650 base oil. Physico-chemical properties of graphene cause that it has been used in many fields, e.g.: electronic devices, photonics and optoelectronics, mechanical engineering, including surface engineering, as well as biomedical engineering, etc.

However, it should be taken into account that graphene is a relatively new material that is measured with such problems as: economic production on an industrial scale, as well as the quality of graphene produced by available methods. The most often and the most easily produced is flake graphene, also called multilayer graphene. It is believed that a structure consisting of several layers (below 10) is graphene. Above this number we are dealing with graphite with completely different properties [2]. Hexagonal boron nitride exhibits large structural similarities to graphene. In addition, it is cheaper to produce compared to graphene. On this basis, it was decided to examine and compare the tribological properties of both materials, using them as additives to the SN-650 oil base.

Research object

The object of research in this article is the SN-650 base oil obtained from the crude oil vacuum fraction, selectively refined, dewaxed with solvents and hydrotreated. The SN-650 base oil is used for the production of lubricants (including gear lubricating oils) and does not contain any refining additives. Thanks to this, it was possible to observe only the influence of additives such as: graphene oxide (GO), reduced graphene oxide (rGO) and hexagonal boron nitride (h-BN) on the tribological properties of a given base not disturbed by any other additions.

Graphene is a building material for all graphite materials. It is a flat structure consisting of carbon atoms (connected to each other at a distance of 0.142 nm), whose crystal lattice is hexagonal with the sp² hybridization. According to [3] graphene has very good mechanical, electrical and thermal properties. Determined for a single graphene layer, the maximum electrical conductivity is 6000 S / cm. In addition, graphene is distinguished by thermal conductivity of around 5,000 W / mK and very high mechanical strength - Young's modulus is 1 TPa. The graphene flake is light and transparent - it transmits about 98% of light, and also has a large specific surface area, which is theoretically 2,630 m² / g. It is very flexible, impermeable to gases, chemically stable, and its specific capacity is 1,350 F / g.

Tab. 1 collate the most important features of graphene oxide and reduced graphene oxide, such as: appearance, bulk density, specific surface area, water solubility and percentage of individual elements. Graphene oxide GO and reduced graphene oxide rGO were obtained from the Institute of Electronic Materials Technology in Warsaw.



Preset parameter			Value		
		Unit	Graphene oxide	Reduced graphene oxiede	
Appearance		-	From light brown to dark brown	From gray to black	
Bulk density		g/cm ³	0,004	0,019	
Specific surface		m²/g	5 (freeze-dried) 11 (spray dried)	266	
Solubility in water		-	Creates homogeneous suspension	hydrophobic	
Composition	Carbon Oxide Sulfur Nitrogen Hydrogen	%	4042 4552 13 <0,3 2,53	7080 1520 <2% <0,3 <2%	

Tab. 1. Selected parameters of graphene oxide and reduced graphene oxide

Source: [4, 5]

As a reference material, hexagonal boron nitride h-BN was used (Figure 3) produced in accordance with the technology developed at the Military University of Technology. According to [1] the addition of hexagonal boron nitride to lubricants can significantly affect the improvement of their tribological properties. In comparison to graphene, boron nitride is characterized by better chemical and thermal stability and is safe to use. Figures 1, 2 and 3 show pictures of the additives being compared, which were made using the scanning electron microscope SEM Quanta FEG.



Fig. 1. Graphene oxide Source: own source





Fig. 2. Reduced graphene oxide Source: own source



Fig. 3. Hexagonal boron nitride Source: own source

Due to their properties - flexibility, good thermal conductivity - graphene can be used as an admixture or addition to lubricants such as oils or greases.

The literature lists three areas of possible use of graphene, related to tribology:

- as a component for creating solid coatings on materials that create a friction pair;
- in composite materials;
- as an addition to lubricating substances in order to improve tribological properties.

These issues are discussed in more detail in the previous work of the authors [6]. Recently, in various research centers, research was conducted on the use of graphene in the lubrication engineering [7, 8, 9]. It is generally believed that graphene can have an impact on improving the tribological properties of oils or greases containing graphene.



Conducting research and analysis of results

The research was carried out according to my own methodology. Graphene oxide and hexagonal boron nitride were mixed with the SN-650 oil base in proportions of 0.05%, 0.1%, 0.5%, 1%, 2% (m / m) and tested on the UNMT (Uuniversal Nano/Micro tester produced by CETR (CA, USA)) test set. Such concentrations were established on the basis of literature analysis [8, 9, 10] and the results of research carried out in the Department of Tribology, Surface Engineering and Logistics of Service Fluids at the Military University of Technology, which showed that the most favorable concentration of h-BN in oil was its 2% content [1, 11].



Fig. 4. UNMT research set. I - bottom drive, II - upper drive, III - device frame, IV - anti-vibration platform, V - thermo-acoustic cover Source: own source

In UNMT (Fig. 4) there is a steel, reference plate (according to GOST9038-73), a ball with a diameter of 3.2 mm (1/8 ") made of 100Cr6 bearing steel is mounted in the spindle. As a result, initial pressures of 5323.6 MPa were generated. Before each measurement, the plate and ball were cleaned with gasoline and acetone. Tab. 2 presents the parameters at which the measurement was made. The lubricant was introduced into the friction area using a glass rod. After each measurement, the diameter of the wear trace on the balls and plates was measured using a Nikon Eclipse LV100 microscope.

Preset parameter	Unit	Value
Load / pressure	N/MPa	150/5323,6
Amplitude	mm	1
Duration of the test	min	15
Frequency	Hz	25
Total number of cycles	-	22 500
Linear speed	mm/s	50

Tab. 2. Parameters at which the nanotester was measured

Source: own source



The graph (Fig. 5) shows the diameter of scars of wear on the balls used in the test. The diameter of the wear scare for pure oil base was 226 μ m. For graphene oxide, the smallest diameter of the scar was observed at a concentration of 2%, while for boron nitride the smallest scar of wear was observed at 1% concentration. For this concentration, the effect of GO and rGO was the same as for h-BN.



Fig. 5. Diameter of traces of wear on the balls Source: own source

Analyzing the list of wear scars on the balls, it was observed that the diameter of wear scars for concentrations of 0.05%, 0.1%, 0.5% is maintained at a similar level. The content of 2% graphene oxide significantly reduced the diameter of scars on the ball (Fig. 6). The addition of reduced graphene oxide only slightly improved the anti-wear properties of the SN-650 oil base. Its impact was the same for 1% and 2%.



Fig. 6. Picture of the scar on the ball: A – pure SN-650 oil base; B – SN-650 oil base + 2% graphene oxide Source: own source



Fig. 7 is a graph showing the width of wear traces on a steel plate. The trace width for pure oil base was 221 μ m. For both graphene oxide, reduced graphene oxide, the smallest traces of wear were observed for the concentration of 2% added in the SN-650 oil base. However, in the case of h-BN, a better effect was obtained for 1% concentration.



Fig. 7. Width of wear marks on a steel plate Source: own source

Fig. 8 shows traces of wear on a steel plate for pure SN-650 oil base and SN-650 oil base with the addition of 2% graphene oxide. It was noted that positive GO at such a concentration resulted in a reduction in the width of the wear trace on the steel plate. In addition, the wear trace is characterized by a lighter shade which may indicate a lower depth of the trace in relation to the trace for pure oil base.



Fig. 8. Picture of the wear traces on the steel plate: 1 - for pure SN-650 oil base; 2 - for the SN-650 + oil base, 2% graphene oxide Source: own source



The addition of more and more graphene oxide to a concentration of 0.5% did not significantly affect on the value of wear, and at a concentration of 1% the width of the scar on the plate is clearly reduced. When comparing the concentrations of individual substances, it was noticed that the mixture of 2% graphene oxide with an oil base reduced the width of wear trace on the plate to the greatest extent. For 1% boron nitride and 1% graphene oxide, these values are the same. For the concentration of 0.05% and 0.1% reduced graphene oxide, no changes were observed, and the value of the wear mark on the plate was the same as for the SN-650 oil base.



Fig. 9. The value of the coefficient of friction Source: own source

In addition to measuring the traces of wear, the coefficient of friction was also evaluated. The coefficient of friction for pure oil base was 0.058. Based on the analysis of the results, it was noticed that the addition GO, rGO and hBN had no significant effect on reducing or increasing the coefficient of friction.

Conclusions

The following final conclusions can be formulated on the basis of the conducted research:

- 1. Graphene oxide and boron nitride can be considered additives that improve lubricating properties of lubricating oil.
- 2. The addition of GO and h-BN noticeably affected the anti-wear properties of the oil base.
- 3. The best results were obtained for the mixture of oil base to which 2% of graphene oxide was added.
- 4. Samples containing 2% boron nitride were characterized by slightly worse properties, compared to samples containing 2% graphene oxide.
- 5. Concentrations 0.05%; 0.1%, 0.5% GO and h-BN did not significantly affect the anti-wear properties of the oil base.
- 6. The addition of reduced graphene oxide slightly less than the flake GO influenced the antiwear properties of the oil base evaluated on the UNMT.



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MECHANICAL DESIGN AND FEM ANALYSIS OF ELECTRIC MOTORCYCLE'S SWING ARM

Wojciech Pawlak^{1*}, Kacper Leszczyński²

¹ Department of Fundamentals of Machine Design and Tribology, Faculty of Mechanical Engineering, Wrocław University of Science and Technology, Wrocław
² Department of Maintenance and Operation of Logistics, Transportation and Hydraulic Systems, Faculty of Mechanical Engineering, Wrocław University of Science and Technology, Wrocław * corresponding author:wojciech.pawlak92@gmail.com

Abstract:

Growing requisition for quick and ecological delivery in food industry requires new approach to the problem of transportation. Electric vehicles are both a solution and a new design issue. What was already designed and used throughout decades, now needs to be changed. Following article presents both mechanical design and FEM analysis of a small electric motorcycle's swing arm designed for food delivery industry. FEM analysis was conducted on couple of different driving conditions, such as: 1G, 1.9G, longitudinal stiffness, torsional stiffness, turning conditions and fatigue. Motorcycle was designed by students for international competitions of SmartMoto Challenge in Barcelona.

Keywords:

electric motorcycle, swing arm, shock arm, FEM analysis,

Introduction

Light Electric Motorcycle project is a series of motorcycles designed by students for SmartMoto Challenge competition. Every year students are challenged with new type of motorcycle. Throughout the years team of students designed and built motorcycles for off-road, food delivery and police. The subject of this article is a swing arm for electric motorcycle designed for food delivery industry. Fig. 1 presents mentioned motorcycle.





Fig. 1. LEM Napoli – students' electric motorcycle for food industry Source: own source

Design boundary conditions

Material chosen for this construction is aluminum alloy 6063 T6, type of suspension is presented in Fig. 2 and characteristics of motorcycle used for calculation is presented in Tab. 1.



Fig. 2. Chosen type of suspension Source: BikeBD [1]



Diameter of a front wheel	18"
Diameter of a rear wheel	16"
Wheelbase	1175 mm
Length of a swing arm; axle to axle	380 mm
Width of the BLDC motor mounting	144 mm
Maximum carrying mass	$m = 200 \ kg$
BLDC motor peak power	2 kW
Maximal tilt in turning conditions	$\tau = 35^{\circ}$
Approximate location of CoG from	b = 300mm
rear axle	h = 767mm
Dynamic longitudinal coefficient of	$\mu_d = 0.7$
friction	
Static longitudinal coefficient of	$\mu_{s} = 1$
friction	
Motor Torque	T = 50 Nm
Front wheel radius	$R_F = 309,6 mm$
Rear wheel radius	$R_{R} = 266,7 mm$
Mass percentage on a rear wheel	$R_{\%} = \frac{p-b}{p} = 74,5\%$

Tab. 1. Motorcycle's characteristics

Source: own calculations

Fig. 3 presents basic geometrical dimensions of a motorcycle. Those geometrical values are based on ergonomic researches described in another publication [2].



Fig. 3. Chassis design and basic geometrical values of LEM Napoli Source: own source

External loads overview

In order to perform FEM analysis, external loads need to be determined. Besides standard gravitational interactions, there is also necessity of calculating forces during turning conditions and



forces for torsional and longitudinal stiffness. All of the forces needed for analysis are listed in Tab. 2.

Load on a front axle	$N_{Sf} = F_{\%} \times m \times g = 501 N$
Load on a rear axle	$N_{Sr} = R_{\%} \times m \times g = 1461 N$
Driving force	$P_r = \frac{T}{R_R} = 187,5 N$
Vertical force of inertia	$N_{tr} = \frac{S \times h}{p} = 122,3 N$
Dynamic load on the front wheel	$N_{acf} = N_{Sf} - N_{tr} = 378,7 N$
during acceleration	
Dynamic load on the rear wheel	$N_{acr} = N_{Sr} + N_{tr} = 1583,3 N$
during acceleration	
Static braking force on a front wheel	$F_f = N_{Sf} \times \mu_s = 501 N$
Static braking force on a rear wheel	$F_r = N_{Sr} \times \mu_s = 1461 \ N$
Total static braking force	$F_B = F_f + F_r = 1962 N$
Dynamic braking force on a front wheel	$F_{Bf} = N_{Sf} + F_B \times \frac{h}{p} = 1781 N$
Dynamic braking force on a rear wheel	$F_{Br} = N_{Sr} - F_B \times \frac{h}{p} = 181 N$
Maximum speed	$v = 65 \frac{km}{h} = 18 \frac{m}{s}$
Minimal turning radius with	$P = \frac{v^2}{2} = 475 m$
maximum speed [3]	$\tan \tau \times g$
Centrifugal force during turning	$F_{1} = -\frac{m \times v^2}{m} = 1373.8 \text{ N}$
conditions	$r_{ctrf} = R = 1373,0$ N

Гаb	2	Loads	acting	on a	motorcycle	•
I av.	4.	Loaus	acting	ona	motoreyere	1

Source: own calculations

FEM analysis

3D model of a swing arm was designed with help of Catia V5 R20 environment and all of the FEM calculations were conducted in Abaqus software. As calculation model, shell model was created based on Catia solid model. Subsequently discrete model was created mainly of S4R elements (19 820 elements) and S3R elements (19 elements), which indicates relatively good quality of discrete model. Regions where bearings of shock absorbers and axle bearings where placed, separate mesh regions were isolated.

G1 case

The most basic analysis to conduct is so called G1 test. It checks how swing arm reacts during maximum load on a rear wheel in normal G acceleration. Formula (1) presents how load acting on a swing arm was calculated. Fig. 4. presents results of an analysis.

$$F_{G1} = R_{9_h} \times m \times g \times \mu_s + N_{tr} = 1583,3N \tag{1}$$

Where:

 F_{G1} [N]-load on a rear axle in G1 conditions,



 R_{96} [%] - mass percentage on a rear wheel, $g \left[\frac{N}{kg}\right]$ - Earth's gravitational acceleration, μ_s - static longitudinal coefficient of friction, N_{tr} [N] - vertical force of inertia



Fig. 4. G1 analysis results: maximum stress: 45,64 MPa, maximum displacements: 0,2 mm Source: own source

G1.9 case

This case concerns maximum possible G acceleration acting on a motorcycle. Acceleration was measured on similar motorcycle with the same electric motor by MyRio accelerometer. After filtering out the noises, maximum value oscillated around 1,9G. Results of G acceleration research are presented in Fig. 5. Stress distribution is identical as in Fig. 4.

$$F_{G1,9} = R_{\%} \times m \times 1.9g \times \mu_s + N_{tr} = 2898.2N$$
(2)

Where:

 F_{G19} [N] - load on a rear axle in G1,9 conditions,

 $R_{\rm \%}$ [%] – mass percentage on a rear wheel,

 $g\left[\frac{N}{kg}\right]$ - Earth's gravitational acceleration,

 μ_s – static longitudinal coefficient of friction,

 N_{tr} [N] – vertical force of inertia





Fig. 5. Maximum G-force research Source: own source

Maximum stress in G1,9 test equals to 83,5 MPa and maximum displacement -0,37 mm.

Longitudinal stiffness

Another load acting on a swing arm that needs to be considered is driving force. It's the force that "push" motorcycle forward, therefore swing arm is compressed. Fig. 6 presents result of analysis.

$$F_{LS} = N_{Sr} \times \mu_s = 1461N \tag{3}$$

Where:

 F_{LS} [N]-maximum load in horizontal direction,

 N_{Sr} [N] – vertical force of inertia,

 μ_s – static longitudinal coefficient of friction



Fig. 6. LS analysis results: maximum stress: 12,2 MPa, maximum displacements: 0,03 mm Source: own source



Torsional stiffness

With longitudinal stiffness, next natural direction is torsional stiffness. To check it, it is needed to establish minimum turn radius with maximum velocity. It is calculated based on tires type, coefficient of friction and CoG of motorcycle with a driver. Formula (4) presents calculation of maximum centrifugal force. Results of analysis is presented in Fig. 7.

$$F_{TS} = \frac{m \times v^2}{R} \times R\% = 1023,5N$$
 (4)

Where:

 F_{TS} [N] – maximum centrifugal force,

m [*kg*] – motorcycle maximum weight,

 $v\left[\frac{m}{s}\right]$ – maximum velocity,

R[m] – minimum radius of turn with maximum velocity,

 R_{96} [%] – mass percentage on a rear wheel,



Fig. 7. TS analysis results: maximum stress: 78,8 MPa, maximum displacements: 2,07 mm Source: own source

Turning conditions

In real life turning conditions, motorcycle is not only exposed on acting of centrifugal forces, but also standard gravitational ones. In this case, calculation is presented in (5) and (6) and resultant force in (7).

$$F_{G1,9} = R_{\%} \times m \times 1.9g \times \mu_s + N_{tr} = 2898,2N$$
(5)

$$F_{ctrf} = \frac{m \times v^2}{R} \times R\% = 1023,5N \tag{6}$$

$$F_{TURN} = \sqrt{F_{ctrf}^2 + F_{G1,9}^2} = 3073,6N \tag{7}$$



Where:

 $F_{G1.9}$ [N]-load on a rear axle in G1,9 conditions,

 F_{ctrf} [N] - centrifugal force,

 F_{TURN} [N]-resultant force acting on swing arm in turning conditions,

 N_{tr} [N] – vertical force of inertia

 μ_s – static longitudinal coefficient of friction

 $g\left[\frac{N}{k_{\sigma}}\right]$ – Earth's gravitational acceleration,

m [kg] – motorcycle maximum weight,

- $v\left[\frac{m}{2}\right]$ maximum velocity,
- R[m] minimum radius of turn with maximum velocity,
- R_{96} [%] mass percentage on a rear wheel,



Fig. 8. Turning analysis results: maximum stress: 100,5 MPa, maximum displacements: 0,46 mm. Source: own source

Buckling

Last significant analysis concerns buckling. Despite general assumptions, that buckling is very unlikely to happen in this kind of constructions, it is important to take it under consideration. In this case, author decided to perform buckling analysis based on turning conditions test, due to the fact, that in this particularly complex test the highest stresses occurred. Results are presented in Fig. 9.





Conclusion

Conducted analysis was important for the process of designing motorcycle. Analysis helped notice most dangerous areas in the swing arm construction and prevent shortened durability problem. In the process of FEM analysis 7 types were specified:

- G1,
- G1.9,
- Longitudinal stiffness,
- Torsional stiffness,
- Turning conditions,
- Buckling,
- Fatigue.

None of the above types of analysis were exceeded. Maximum stress in above analysis types is equal 100,5 MPa. Maximum permissible stress was equal to 133.3MPa. Maximum deflection is equal to 2,07 mm. Final weight of a motorcycle's swing arm is equal 0,83 kg.

Analysis type	Stress [MPa]	Deflection [mm]	Permissible stress
v v 1			[MPa]
G1	45,64	0,2	133,3
G1,9	83,5	0,37	133,3
LS	12,2	0,03	133,3
TS	78,8	2,07	133,3
Turning	100,5	0,46	133,3

Tab 3. Summary table

Source: own source 100



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INVESTIGATION OF CHANGES IN THE OXIDATION RESISTANCE OF ENGINE OIL DURING OPERATION

Kacper Pawlikowski

Military University of Technology, Faculty of Mechanical Engineering, 00-908 Warsaw, ul. gen. Sylwestra Kaliskiego 2 corresponding author: kacper.pawlikowski@wat.edu.pl

Abstract:

The oxidation resistance test can give knowledge about the remaining antioxidant additives, which small amount in the oil could lead to rapid changes in the oil parameters and could damage the engine. The article describes the entire oxidation reaction process and presents the results of oxidation resistance tests together with formulated conclusions. The tests were carried out according to our own methodology based on the PN-EN 16091 standard and the PetroOXY instruction manual. It was found that the pressure change curves during the oxidation resistance test of most samples are linear, which may mean that the antioxidant additives are not exhausted. In the case of several samples, however, they have curvilinear character and can only be described by means of a polynomial, in these samples the additives have probably been degraded.

Keywords:

PetroOXY, oxidation, engine oil

Introduction

The engine oil in the operation of the internal combustion engine undergoes continuous aging, one of the main factors that causes oxidation. Over time, the oil undergoes an oxidation process, usually starts with the degradation of antioxidant additives, the time of their disappearance is called the induction period. The consequence of oxidation processes is, among others increase of oil viscosity, formation of organic acids, sludge and sediments and loss of other properties. Oxidation is a complex reaction and can be divided into three key stages: initiation (start of oxidation), propagation (spreading) and ending [1].

In the initiation phase, processes occur that lead to the formation of free radicals. They are the result of the reaction of hydrocarbon molecules, mainly oil. An additional factor that facilitates are catalysts, substances that increase the rate of chemical reactions. Free radicals are molecules that have unpaired electrons. They are susceptible to reactions with hydrocarbons and other molecules. Their formation leads to the transition to the propagation stage. The catalysts in these reactions may be particles of worn metallic engine parts. Metal ions such as copper, cobalt, chromium, iron etc. cause acceleration of the oxidation reaction [2]. Nitrogen oxides, ultraviolet radiation and high temperature also increased the process of formation of free radicals. At low temperatures, chain



reactions are slow, but with its growth they may even be multiplied. However, the main catalyst at each stage of oxidation is oxygen. It can get from the air, but also from other particles, such as water.

The propagation step refers to the reaction of free radicals, they combine with other molecules and create new products. During this process, oxidized compounds are formed, such as: aldehydes, ketones, alcohols and water. At this stage, antioxidants also act, act as chain breakers and break down oxidized compounds. As in the previous case, the catalysts are mainly oxygen and temperature [1].

The last stage, i.e. ending the oxidation, can be divided into "negative" and "positive". The positive antioxidants inhibit the formation of undesirable substances in the oil, by breaking the bonds and reactions with free radicals, which results in the formation of stable and inert by-products. Antioxidants, however, are broken down during their work, which is why their complete degradation leads to the negative effects of oxidation. In the second case, oxygen compounds continue to react with oxygen, and this leads to the formation of acids, esters and water, this process is further accelerated by high temperature. In addition, a polymerization process takes place in the oil. It is a reaction of low molecular weight compounds that react by themselves to form molecules with a much higher molecular weight [3], and other byproducts such as water, glycol or methanol are also released by polycondensation. Products of acidic character are created, sludges (low temperature sediments), lakes (high temperature sediments) as well as deposits generated from the products of burning fuel and lubricating oil and thermal decay [4]. As the amount increases, the viscosity of the oil begins to increase, additionally together with the water they cause corrosion of the surface of the engine components.

The above premises are reasons of testing the resistance to oxidation of overworked oils. This can give knowledge about the remaining additives, which small amount in the oil further used in the engine, could translate into a rapid change of oil parameters, and could damage to the engine.

Research methodology

The determination was made at the station shown in Fig. 1.





Fig. 1. Stand for testing oxidation resistance with the PetroOXY apparatus Source: own study

The study was based on own methodology, based on the PN-EN 16091 [5] and instructions [6] for PetroOXY apparatus operation. The test consists in determining the time at which a 10% pressure drop will occur from its maximum value at a fixed temperature in the test chamber. The pressure was generated by oxygen, and the pressure drop was caused by the oxygen absorption of a sample of the engine oil under investigation as a result of the oxidation reaction.

The result of the test is the arithmetic mean of two measurements, not differing by more than the repeatability of rOU determined according to the formula (1) [5]:

$$rOU = 0,0288 \cdot OU + 0,4965 \tag{1}$$

where:

rOU – repeatability of resistance to oxidation [minute];

OU - medium resistance to oxidation from two measurements [minute].

Results and discussion

Engine oil according to SAE 5W/30, API CH-4 /CI-4/CJ-4 and ACEA E4/E6/E7/E9 standards was given to the tests. All oil samples were taken from the MAN truck lubrication system. The manufacturer of these vehicles recommends using it in oil for a period of 12 months or up to 100,000 km for engines of the D2676 family and 60,000. km for D0836 engines [7]. The list of samples, including vehicle models, mileages and results of oxidation resistance tests are presented in Tab. 1.



Sample designation	Vehicle model	Engine identification	Time between exchanges, months	Total vehicle mileage, km	Mileage from the previous oil change, km	Resistance to oxidation, minute
Fresh oil (OŚ)	-	-	-	-	-	1064,5
1	TGX 18.480	D2676LF45	5,5	249,2	62,9	931,9
2	TGX 18.480	D2676LF46	11,7	171,5	77,8	694,9
3	TGS 18.440	D2676LF46	8,9	269,1	90,1	765,5
4	TGS 18.440	D2676LF46	8,6	269,0	81,7	751,9
5	TGS 18.440	D2676LF46	11,9	163,7	85,4	378,7
6	TGX 18.480	D2676LF45	5,3	113,4	53,5	927,5
8	TGS 18.440	D2676LF46	5,0	159,0	82,9	548,1
9	TGM 13.290	D0836LFL67	12,7	1,4	1,4	823,8
12	TGX 18.440	D2676LF26	9,5	363,8	97,6	903,7
13	TGX 18.440	D2676LF26	18,2	367,4	85,3	916,9
14	TGX 18.440	D2676LF26	5,2	253,4	82,0	924,1
15	TGM 13.290	D0836LFL76	8,9	2,1	0,4	937,1
16	TGM 13.290	D0836LFL67	11,7	2,1	1,1	853,6
17	TGM 13.290	D0836LFL76	11,5	3,2	1,3	875,8
18	TGM 18.340	D0836LFL68	11,3	1,1	1,1	822,5
19	TGX 18.440	D2676LF46	12,4	178,3	89,1	733,6
20	TGM 13.250	D0836LFL63	11,4	54,7	9,8	853,7
26	TGX 18.480	D2676LF45	10,3	227,1	130,6	196,2

Tab.	1. I	ist	of	sam	ples
r ao.	1.1	130	O1	Sam	pics

Source: own study

The oil worked in engines with different capacities and powers. All engines had a Common Rail injection system, differing in torque, capacity and power, their parameters are shown in Tab. 2.

Engine type	Engine capacity cm ³	Engine power, kW (KM)	Torque, Nm		
D0836 family					
D0836LFL63		184 (250)	1050		
D0836LFL67	6 871	213 (290)	1150		
D0836LFL68		250 (340)	1250		
D0836LFL76		213 (290)	1150		
	D2676	family			
D2676LF26		324 (440)	2100		
D2676LF45	12 400	252 (480)	2200		
D2676LF46		555 (480)	2300		

Tab. 2. List of engin	es
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Source: own study

Fig. 2 shows the pressure change curves of the tested samples in the PetroOXY apparatus as a function of time. The first 100 minutes of the oxidation resistance test were not included in all figures, at which time the sample was heated, and the oxygen pressure was increased in the chamber.



This time had no significant impact on the results of the research and analysis. In the drawings, the dashed line shows the trend lines and presents the equations of the determined regression functions.



Fig. 2. Pressure variations in the test chamber for all oils sample Source: own study

Samples can be divided into those that can be described by a linear function and those that can be described by a polynomial function. Samples that can be described by a linear function (1, 3, 4, 6, 9, 12, 13, 14, 15, 16, 17, 18 and 20) were characterized by high resistance to oxidation ranging from 765.5 to 937.1 minutes (1064.5 for fresh oil), there was also no sharp pressure drop in the test chamber. This means that the antioxidant additives contained in the tested samples fulfilled their function and inhibited the formation of undesirable substances. The remaining samples (2, 5, 8, 19, 26) were described by the polynomial function (they had too little coefficient of determination to be able to describe them with a linear function). They observed a rapid drop in pressure in the chamber (especially in samples 5, 8 and 26), which could be caused by the exhaustion of antioxidant additives in the oil.

Fig. 3 and 4 show exemplary pressure change curves described by a linear function together with equations and a coefficient of determination.





Fig. 3. Pressure variations in the test chamber for a fresh oil sample Source: own study



Fig. 4. Pressure variations in the test chamber for samples 17 and 18 Source: own study

In Tab. 3 all samples were collected, which can be described by a linear function and the coefficients of the regression function and the results of oxidation resistance tests in minutes are presented.



Sample number	Coefficients of the regression function			Coefficient of determination	Resistance to
	а	angle α , °	b	\mathbb{R}^2	oxidation
OS	-0,0998	-5,7	1035,4	0,997	1064,49
1	-0,1085	-6,2	1026,0	0,9996	931,93
3	-0,1398	-8	1038,6	0,9929	765,45
4	-0,1388	-7,9	1035,3	0,993	751,92
6	-0,1115	-6,4	1032,3	0,9986	927,46
9	-0,1241	-7,1	1028,6	0,9995	823,83
12	-0,1154	-6,6	1031,6	0,9978	903,65
13	-0,1171	-6,7	1036,1	0,9992	916,91
14	-0,1165	-6,6	1033,9	0,9987	924,07
15	-0,1091	-6,2	1026,5	0,9994	937,12
16	-0,1261	-7,2	1037,1	0,9997	853,60
17	-0,1238	-7,1	1035,9	0,9993	875,82
18	-0,1268	-7,2	1029,8	0,9994	822,46
20	-0,1182	-6,7	1029,0	0,9975	853,74

Tab. 3. Values of linear regression coefficients of pressure changes in the PetroOXY test chamber for the tested oil samples

Source: own study

The determined values of coefficients "b" of the linear regression function are in the range from 1026.0 to 1034.6 and depend on the value of the ambient temperature at the start of the test.

Values of "a" coefficient range from -0.1085 to -0.1398 (-0,0998 for fresh oil), which corresponds to the slope angles of simple regression functions from -6.2 $^{\circ}$ to -8.0 $^{\circ}$. The correlation between the values of the coefficient "a" and the value of resistance to oxidation is 0.95. Such a high correlation coefficient gives the chance to build a mathematical model, pressure change curves for samples with high resistance to oxidation.

Fig. 5 and 6 show exemplary pressure change curves described by a polynomial function.




Fig. 5. Pressure variations in the test chamber for samples 8 and 19 Source: own study



Fig. 6. Pressure variations in the test chamber for sample 26 Source: own study

In Tab. 4 all samples were collected, which can be described by a polynomial function and the coefficients of the regression function and the results of oxidation resistance tests in minutes are presented.

Tab. 4. Values of regression coefficients in the form of a polynomial of pressure changes in the PetroOXY	l test chamber
for the tested oil samples	

Sample	Coefficients of the regression function					
number	a	b	с	d	е	R ²
2	0	0	-9.10-5	-0,0701	1021,4	0,9984
5	-5.10-8	4.10-5	-0,0109	1,1111	980,2	0,9861
8	0	-1.10-6	0,0007	-0,2427	1037,9	0,9931
19	0	0	-0,0001	-0,0471	1028,1	0,9959
26	-2.10-6	0,0007	-0,1052	6,9891	854,6	0,9935

Source: own study

The oxidation resistance of the tested samples of Aggregated Total Rubia SAE 5W / 30 oil ranges from 196.2 to 937.1 minutes.

The smallest resistance to oxidation was demonstrated by the sample No. 26, the pressure change curve during the test was the polynomial function. The sample was taken from the engine with the highest mileage since the previous exchange (130.6 thousand km) and worked in a 480 HP engine (MAN D2676LF45).

It should be noted that all other samples described with the polynomial function worked in D2676LF46 engines with the same power as the D2676LF45 model. Compared to other samples taken from these engines, they had similar waveforms, but they were characterized by a longer period between exchanges (not counting sample 8).

Interesting is that the samples that worked in D2676LF26 engines, despite similar waveforms as D2676LF46, their resistance to oxidation slightly changed in relation to fresh oil. It must be assumed that they have not yet used up antioxidant additives, which could be due to different operating conditions and less engine load than the previously described samples.

Samples which were taken from the D0836 family engines were too small to be able to determine the impact of this factor on qualitative changes. In this group of samples, it can only be seen that the sample 15 which has the highest resistance to oxidation also has the shortest period between exchanges. The influence of storage time on changes in resistance to oxidation, but it is a single sample, equally well the effect of testing could have flooded engines with oil from another batch that differed in composition.

Conclusions

It was found that the pressure change curves during the oxidation resistance test of most samples are linear. In the case of several samples, they have curvilinear character and can only be described by means of a polynomial.

In the samples described with the linear function there was no sharply pressure drop in the test chamber. This means that the antioxidant additives contained in the tested samples have fulfilled their function and inhibited the formation of undesirable oxidation products.



A large correlation was found between the values of the coefficient "a" of the linear function and the value of resistance to oxidation. It is 0.95.

In the samples described by the polynomial function, after some time, a rapid drop in pressure was observed in the test chamber (especially in samples 5, 8 and 26). Literature analysis allows to conclude that in these samples the antioxidant additives have ended and intensive oxidation of the oil components has occurred.

The smallest resistance to oxidation was demonstrated by the sample No. 26, the pressure change curve during the test was the polynomial function. The sample was taken from the engine with the highest mileage since the previous exchange and worked in the engine with the highest power (from those described in the article). It can be assumed that these were the main factors that caused this.

Intensive oxidation of oil components occurred mainly in samples of oils used in engines D2676LF46 and 45, both models have more power, which translates into heavier driving conditions. The remaining samples from these engines, despite similar runs, had shorter intervals between exchanges, which could lead to the conclusion that intensive use in the short term causes less oil consumption than longer use, but at a lower intensity.

The results of the conducted tests cannot be general conclusions, additional tests should be performed on a larger number of samples and also other engine oil properties such as the basic number or infrared analysis should be taken into account.

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IMMUNOLOGICAL INFERTILITY- WHAT'S THE BIG DEAL?

Agata Pilarska^{*}, Klaudia Paryska

Chair and Department of Immunology and Serology, School of Pharmacy with the Division of Laboratory Medicine in Sosnowiec, Medical University of Silesia in Katowice *corresponding author: agat.pilarska@gmail.com

Abstract:

Infertility is defined as the inability of couples to achieve pregnancy, despite having regular unprotected sexual intercourse. There are many factors, which will increase infertility risk. This study was designed to investigate the problem of men's infertility influenced by the presence of antisperm antibodies (ASA). ASA are immunoglobulins with antibody activity against a sperm antigens. Presence of those antibodies is one of the most frequent immunologic factors proposed for male infertility. They are detected in blood serum, seminal plasma and sperm-bound. Main function of antisperm antibodies is connected with dysfunction of spermatozoa and that is the reason of disruption of particular steps of fertilization. In conclusion, male infertility can be caused by immunological factors. Fortunately, a presence of ASA do not determine permanent infertility - appropriate diagnosis and treatment strategy of infertile males with ASA increase chances for fertilization.

Keywords:

infertility, antisperm antibodies, sperm, immunology

Introduction

Infertility is a condition of the reproductive system that causes inability to conceive pregnancy, despite a regular unprotected sexual intercourse with partner with an average frequency of 3-4 times per week [1].

Either women or men can be responsible for infertility. In about 10–20% of the cases, no definitive cause has been identified. The main factors of almost half of the diagnosed cases of male infertility are connected to a small amount of semen and its abnormal morphology. Moreover, some diseases may act on human fertility – due to effective antitumor therapy male fertility is reduced by half in comparison to a healthy men. Infertility is also associated with their general state of health – infertile men are exposed to the other diseases, such as coronary artery disease, diabetes, prostate cancer or testicular cancer. Alcohol, drugs and smoking are elements that affect male fertility. 9–36% of the cases have been attributed to the production of anti-sperm antibodies (ASA) in men [2-5].



Antisperm antibodies (ASA) are immunoglobulins of IgA, IgM and IgG with antibody activity against the sperm antigens. Presence of ASA is one of the most frequent immunologic factor responsible for infertility. They are detected in blood serum, seminal plasma and sperm-bound [2, 3, 6, 7].

Every fifth couple in Poland has trouble conceiving - 40-60% of these cases is mainly or partly due to men's procreative ability. Percentage of patients with ASA in infertile men shall be 5-25% and in fertile male - 1-2%. Percentage of ASA in patients, whose infertility's aetiology is unknown reaches 14-40% [2, 6-8].

ASA: Occurrence, mechanism of action and complications

The reasons of occurrence of ASA involve: disruption of the blood-testis barrier, varicoceles, cryptorchidism, immunosuppressive factors deficiency, which are important in process of active tolerance towards germ cells of men, or congenital obstruction of male reproductive system. Acquired obstruction of male reproductive system caused by vasectomy, inflammatory process in reproductive organs, testicular trauma, multiply biopsy. The other reason may include reproductive system infections including specific infection with *Chlamydia* or *Neisseria gonorrhea* or non-specific, resulting in coming into existence cross-reactions with some antigens of spermatozoon [2,6].

The pathogenesis of male infertility can be reflected in defective spermatogenesis, sperm transport, abnormal sperm phagocytosis or defective sperm functional parameters, ASA may block the initiation of embryo cleavage. Infertility mechanisms of ASA have also involved virtually all components of sperm and egg interaction, from hampered sperm capacitation to altered sperm motility, to diminished sperm–oocyte binding and faulty zona pellucida penetration.

Antisperm antibodies are immunoglobulins of IgA, IgM (located on head and in the end of flagellum) and IgG. They are detected in ejaculate and are able to coat spermatozoa in specific locations: on head, where they interfere with the interaction of ovum, middle place or the end of flagellum, impairing spermatozoon's movements. This location is conditioned by occurrence of individual antigen determinants. Antisperm antibodies demonstrate capacity to cross-linking spermatozoa and also anchoring them to glycoprotein cervical mucosa micelles that interact with the Fc fragments of IgA molecules. Consequently, the "shaking phenomenon" is observed - spermatozoa change their progressive movements into jerkinglike and shaking movements, without any progression [2, 3].

There are three categories of immunoreactive sperm antigens:

1. Antigens unrelated to fertilization – recognized by natural, non-specific antibodies from either fertile or infertile men; regardless of the presence of ASA. Cross-reacting antibodies can bind sperm, erythrocytes, lymphocytes and bacteria. These antigens are not important in the process of fertilization.

2. Relevant antigens in the process of fertilization – they are recognized by antibodies, which are present in infertile people. These antibodies are produced as a response to the other, bacterial antigens and are reactive in respect to either sperm cells or somatic cells.



3. Sperm specific antigens – recognized by specific sperm antibodies (affects infertile people) [2, 3].

Sperm's defense mechanisms against immunological diagnosis involve: blood-testis barrier and blood- epididymis barrier, immunosuppressive factors present in the testis tissue and epididymis tissue, immunological tolerance to cells after reaching sexual maturity and immunosuppressive properties of plasma and semen.

ASA effect contribute to the disorders of spermatozoon's function. It's responsible for disruption of fertilization process, suppression of progressive movements of sperm cells, caused by agglutination, suppression of maturation's and capacitation's processes, suppression of ability to sperm and egg interaction and suppression of sperm's maturity process and damaging developing spermatozoon in testicles as a result of presence of, but only during autoimmunological testicles' inflammation [2, 4, 6].

Diagnosis and treatment of antisperm antibodies

Diagnosis

Detection of antisperm antibodies should therefore be considered as an essential element of all infertility examinations. Commercially available ASA assays either measure ASA bound to sperm or measure ASA in solution. Those assays include ELISA, immunobead assays (IBT) or mixed antiglobulin reaction (MAR).

An ELISA for examination of antisperm antibodies consist in antibody-enzymeimmunoglobulin complexes. ELISA is both specific and quantitative. Albeit, this test detect also intracellular exposed antigens and it may lead to preventing correct results' interpretation. In addition, ELISA is limited by the amount of time it involves, its poor sensitivity and cost.



Another option of ASA detection is IBT, which detects antisperm antibodies in several biological samples: blood and semen. This method is widespread and used in many laboratories. The coated beads are mixed with fresh, washed or unwashed sperm samples and ultimately bind to sperm bound ASA. Incubated with polyacrilimide beads sperm samples are examined under a microscope in the laboratory. Motile sperm count binded with immunobeads are assessed. Advantages of IBT assay include good sensitivity and ability to detect the isotype. The disadvantages include a high cost and interpretation' difficulty.





Fig. 2. The IBT assay

Source: http://faculty.washington.edu/cmuller/MFL/advanced-tests--procedures/anti-sperm-antibodies.html

The MAR assay is direct mixed agglutination test, which is similar to IBT assay. MAR is used to detect the presence of either IgG or IgA, sensitivity of the test is higher for IgG, on the surface of the spermatozoa. The test material are sperm, blood serum and seminal plasma. MAR test is performed by mixing fresh, untreated sample with latex particles that have been coated with human antibodies. Antiserum specific to the immunoglobulin used to coat the erythrocytes is added, and sperm-erythrocyte agglutination occurs in the presence of ASA. The agglutination may be determined by light microscopy. Advantages of MAR testing include good specificity and ability to use viable sperm. The disadvantages include an unknown sensitivity, high cost and inability, or limited ability, to provide information about location and ASA binding. Additionally, the test is challenging to interpret [4, 6, 9, 10].



Fig. 3. The MAR assay Source: https://sansazaroditeljstvo.org.rs/marasa-test-za-nju-i-njega/



Treatment

Several strategies are used in an effort to improve the potentially deleterious effects of ASAmediated infertility: treatment including systemic corticosteroid or ciclosporin. There are also laboratory technics, such as sperm cleaning, sperm selection with the use of immunomagnetic methods, immunobeads and exploitation of proteolythic enzymes. Using one of those methods can result in side effects. Furthermore, these methods are expensive, invasive and sometimes are not entirely effective [2, 3, 8].

Conclusion

Summarizing the gathered information about ASA, authors deduce that men's infertility can be caused by immunological factors. Likewise, diversity of ASA exists and their effects on fertility in infertile males. It leads to the conclusion that men can be responsible for inability of having children. Fortunately, a presence of antisperm antibodies does not determine permanent infertility - an appropriate diagnosis and treatment strategy for infertile males with ASA increase the likelihood of fertilization.

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DEVICES SUPPORTING GAIT REEDUCATION

Wiktoria Sapota^{*}, Sebastian Stach, Zygmunt Wróbel

University of Silesia in Katowice, Faculty of Computer Science and Materials Science, Institute of Computer Science, Bedzinska 39, 41-205 Sosnowiec, Poland * corresponding author: wiktoria.sapota@us.edu.pl

Abstract:

Emerging reports in recent years concerning mainly neurological diseases and broadly understood diseases present their negative impact on patients' walk. The realization of research in this direction brings a number of important advantages influencing the planning of the patient's convalescence process. It also turns out that the additional support obtained through the use of mechanical and semi-automated rehabilitation devices (including robots) is often a key role in the success of therapy and its duration. This article is about the availability of current technological solutions supporting the process of walking reeducation or restoring its regularity in case of pathology. There is a discussion on the appropriateness of using individual robotic solutions in the process of rehabilitation and the direction of development in this field.

Keywords:

gait, walking reeducation, rehabilitation, robotics in rehabilitation

Introduction

The last decades abounding in the dynamic development of exact and technical sciences have brought technological solutions serving man in many spheres of life. Recently, it can be noticed that the tendency to introduce innovative inventions and concepts only for the needs of the armed forces significantly weakens. Unobstructed access to current research in almost every field and the increasingly less complex procedure of acquiring broadly understood resources necessary for project implementation contributes to the design of solutions aimed at a specific problem, intended even for a small audience. Among all dynamically developing aspects of life such as economy, education or security, progress in medicine still plays a fundamental role. A multitude of issues and the complexity of the subject matter of this field seem to be an endless source of discoveries and solutions aimed to contribute to the improvement of the quality of human health and life. Arriving at an unambiguous definition of priorities and the only right direction of progress in this area would undoubtedly pose difficulty. This is a highly subjective matter: for the researcher, it depends on the available interests and means, and for the society - on the personally examined accidents.

There is no doubt that regardless of age, gender, placement in the social hierarchy, religion, or economic status, the possibility of independent implementation of motor functions plays an absolutely fundamental role for humanity. The overall fitness and the ability to move the body, and



importantly - without help of other people - is the absolute foundation for the ability to freely perform consecutive activities in everyday life. Lack of possibility of independent movement or any other limitation of movement possibilities causes a significant impact on the mental state of an individual: weakening self-esteem, sense of uselessness, an almost burdening feeling of gratitude towards others, and even tendency to depression. Considering the importance of these problems and possible consequences, it seems necessary to prevent the emergence of such conditions or to eliminate them as soon as possible. As it would be impossible to prohibit man from carrying out activities that would expose one to an accident, and thus damage of a body (it would mean total inactivity). The only correct solution will be to develop more and more effective methods of treatment and physical rehabilitation.

Gait disturbance - classification

Gait is a complex physical activity, the components of which are numerous activities of the nervous system, responsible for locomotion and balance. Gait assessment is considered the best single test of nervous system dysfunction, because all disorders are a frequent manifestation of existing diseases. The patient's gait reveals irregularities not only in the field of simple motor functions, such as muscle strength and tension, but also in coordination and other functions of the cerebellum, basal ganglia and frontal lobes, as well as sensory disorders and broadly understood cognitive functions. Possible gait pathologies may be caused by a variety of factors, which contributed to the formation of many classifications of disorders. The starting point for beginning the treatment and planning the physiotherapy process is the clinical picture, aetiology or pathogenesis of these disorders. There is a division into three anatomical and pathophysiological levels of gait disorders, widespread in the 1990s: low, middle and highest [1].

Lower level gait disorders lower level gait disorders (LLGD) result from damage to the peripheral motor organs or sensory systems. To a large extent, this mainly refers to deep sensing and sensory organs, such as sight and balance. An example of LLGD are gait disturbances occurring in inflammation and other joint diseases, in neuromuscular diseases, profound sensory disturbances, visual disturbances or vestibule-bony labyrinth system disturbances. Damage to deep brain structures: thalamus and basal ganglia, brain stem and cerebellum is associated with improper integration of sensory stimuli into a 'spatial map' and means the occurrence of middle level gait disorders (MLGD). The higher level gait disorders (HLGD) denotes the occurrence of: cautious gait, frontal ataxia, psychogenic gait disturbances, subcortical and frontal disturbances of balance. Depending on the development/regression of the disease, the qualification for a particular group may change. For example, in the course of progressive supranuclear palsy, patients initially present subcortical disturbances or impairment of gait initiation, and with the duration of the disease, the features of frontal ataxia appear. In some diseases, for example in Parkinson's disease, gait disturbances may occur at the same time from two levels, and in case of comorbidities, even from three levels. Another [2] classification approach, published in 2004, distinguishes 9 clinical gait patterns [Tab. 1].



Type of gait	Special features						
atavic gait	irregular rhythm, shortening of the pace, widening of the base typical for cerebellar and sensory						
ataxic gait	ataxia or chorea;						
	loss of movement smoothness, rigidity of the lower limbs and torso, reduction of trunk rotation,						
rigid gait	shortened step, narrow or widened base, reduced range of motion in the joints of the limbs), occurring						
	in spasticity, parkinsonism, dystonia, and also in the multi-infarct syndrome;						
propulsive gait	for example, foot drop, waddling gait) in the course of muscle diseases, polyneuropathy and damage						
propuisive gait	to the corticospinal tract;						
turning gait	change in one-way walking direction in diseases of the vestibule-bony labyrinth system and						
turning gan	cerebellum;						
	difficulties in starting and changing the direction of walking), typical for parkinsonism, multi-infarct						
freezing of gait	syndrome, normotensive hydrocephalus						
	and other damage to the frontal lobes;						
gait on an	in diseases of the cerebellar worm, but also in other injuries of the cerebellum						
extended basis	and in a multi-infarct syndrome;						
narrow base	in Parkinson's disease or in spasticity.						
gait,	In rankinson's disease of in spasterty,						
cautious gait	slow, short step and rotation of the whole body, characteristic of subcortical lesions of the white						
	matter, but occurring in many other diseases, especially those progressing with anxiety;						
bizarre gait	a bizarre pattern of gait, deviating from the ones described above, which includes psychogenic gait,						
bizarie galt	but also the gait of people with dystonia or one caused by fear of falling						

Source: J. G. Nutt, R. B. Horak. *Classification of balance and gait disorders,* in: Clinical *disorders of balance, posture and gait* (second ed.), A. Bronstein, T. Brandt, MH Woollacott, JG Nutt, London: Arnold, 2004

Diagnostics and rehabilitation

The exact description of the type of developed disturbances and pathologies of gait requires careful subjective and objective examination, including neurological examination and detailed assessment of the motor system [3]. Due to the number and types of diseases affecting (directly or indirectly) the motor apparatus, a uniform approach to gait analysis has not been developed yet. The basic criteria for the selection of the tool defining the abnormalities are mainly factors related to the patient's disease and the limitation of the mobility apparatus caused by it. It is essential that the examination carried out should be characterized by simplicity and execution time causing no problems for the patient. The results obtained should be clear, easy to analyse and comparable for a group of patients by introducing the standardization of certain parameters. The cost of the test, which should not be an obstacle to its accessibility and its regular performance, is also significant [4].

In order to enable a patient to regain natural gait patterns, it is necessary to subject them to the process of gait re-education based on the care provided by specialists: physicians and physiotherapists, of comprehensive character, fully adapted to individual needs and capabilities of the patient. Re-education includes, above all, detailed functional tests (qualitative and quantitative gait analysis), assessment of physiology and pathology of gait, assessment of the patient's potential in terms of possible recovery of the gait function. The need to implement rehabilitation provision (periodically or permanently), schedule preparation as well as other available forms of therapy



conducted as part of a multidisciplinary team are also taken into consideration. With the use of therapy, at specific intervals, the existing effects of work should be verified, and the strategy adjusted to the subsequent stages. One of the most important elements of re-education is the restoration of correct gait patterns, ensuring safety and efficiency in the performed activity. In order to achieve an appropriate and permanent effect, this process should be gradual. Possessing the results of functional tests, regularly assessing the progress in rehabilitation, the team should lead the patient to the maximum improvement of gait function available to them. In order to maintain the recovered ability to walk (or to eliminate the existing pathology), it is necessary to implement exercises that maintain the improvement attained. They are also aimed at counteracting possible secondary changes (contractures, decubitus ulcers) and are also carried out as part of outpatient and home rehabilitation [5-11], and ultimately telerehabilitation [4].

Pathologies of gait resulting from neurological disorders often have a negative impact on the patients' quality of life. The recovery of walking skills becomes the main goal of the rehabilitation process. Gait re-education is usually a long-lasting, tedious and complex process, which apart from an appropriate diagnosis and assumed action plan requires the cooperation of medical specialists working within a multidisciplinary team, with particular emphasis on physiotherapists. Most often, traditional gait re-education is based on the involvement of several physiotherapists at the same time with one patient. A limited number of specialist personnel is therefore one of the main reasons for searching for technical solutions that facilitate the process and increase the efficiency of using limited human resources [4]. To overcome the problems associated with conventional physical therapy, in recent years there has been an intense technological development of robotic devices, and the rehabilitation of robots has been proven to play an important role in improving the ability to walk [12].

The use of robotics in gait re-education

Broadly understood electromechanical systems and robots are mainly used in the rehabilitation of gait in neurological disorders. In such cases, the device relieves the physiotherapist in the process of gait re-education and this is one of the basic advantages of using modern technologies in the rehabilitation process [Tab. 2]. A commonly used method is also a conventional training on the treadmill - mainly for patients who do not tolerate physical effort or have difficulty in walking. This type of training requires the presence of a minimum of two physiotherapists, whose task is to assist the patient and continuous gait correction.



The benefits of robot therapy	Disadvantages of robot therapy
• partial automation of the therapeutic and	 recognition of rehabilitation robotics as "therapy
diagnostic process,	of the future" and postponing its
• repetitive, assisted exercises, using dynamic strain	implementation,
relief systems,	• high price of some solutions, especially stationary
• the possibility of a robot cooperating with the	ones,
patient's intention (bio-cooperative control	• in the case of stationary robots: large sizes
concept),	(sometimes space requirements exceeding, for
• guiding physiological or close to physiological	example, the height of standard rooms),
walking movement	stationary therapy, no possibility of training to
(taking into account the patient's limitations),	walk up the stairs,
• real-time monitoring of the quantity and quality	• less than fully understood mechanisms of the
of performed tasks and patient's progress during	process of self-healing and brain plasticity and
consecutive therapeutic sessions,	their long-term effects,
• use of built-in gait analysis systems, which sets a	• less than fully investigated long-term effects of
limit on	using rehabilitation robots,
the number of additional tests and increases the	• insufficient number of reliable and repeatable
objectivity of assessing therapy results,	clinical trials on large groups of patients,
• selection of therapy parameters and their	especially in the field of therapies combining
correction in line with progress,	different methods, which reduces their
• biofeedback (e.g. using Virtual Reality) ensures	importance using the Evidence Based Medicine
increased patient's motivation,	paradigm (EBM),
• user and service safety, also in case of, for	• the potential need to develop new, more sensitive
example, patient's fainting,	and computerized diagnostic tools dedicated to
• use in telerehabilitation,	patients rehabilitated using rehabilitation robots,
• the possibility of extending the therapy with	• the need to train staff (both medical specialists
haptic (tactile) interfaces,	and engineers), patients and their
• possibility of deploying in patients with deficits	families/caregivers,
regarding only one lower limb (asymmetric leg	• the need to create clinical guidelines,
operation),	• the need to create new legal regulations, including
• possibility of using in patients with consciousness	the safety of using rehabilitation robots and
disorders.	their use in telerehabilitation.

Tab. 2. Advantages and disadvantages of using robots in the rehabilitation process

Source: E. Mikołajewska, D. Mikołajewski, Wykorzystanie robotów rehabilitacyjnych do usprawniania, Niepełnosprawność – zagadnienia, problemy, rozwiązania, 2013, Vol. 4 (9), 21-44.

Despite the widespread use of this method, it is common knowledge that this type of rehabilitation is characterized by a significant difficulty in maintaining the ideal gait pattern during the exercise and its repetition. These problems are eliminated by the implementation of robots in the treatment process, besides - the therapy turns out to be much more effective and less expensive [13]. Appropriate design and programming of the robot allows the patient to be given a repeatable walking pattern in a safe environment, without exposing them to a fall. Of course, the use of the electromechanical system requires verification of the patient: general condition, type and degree of gait disturbance, exercise tolerance, the presence of pressure ulcers and skin lesions. Gait rehabilitation with the application of robots is also effective for patients after spinal cord injury [14]. The improvement of gait function in electromechanical systems is affected by the time of



inclusion of this type of rehabilitation and the extent of posttraumatic spinal cord injury [15, 16, 17]. The literature clearly notes coherence in the statement whereby gait therapy with the application of robots improves the gait function primarily after spinal cord injury, after brain stroke, as well as for patients with cerebral palsy, multiple sclerosis and craniocerebral injuries [12, 14]. Despite the relatively obvious advantages and optimistic attitude towards the application of robots in motor therapy, aspects related to the current state of research, the unpredictability of therapy effects in the long-term context and the necessity to create clinical guidelines should also be considered.

The applied rehabilitation systems can be divided into three main groups: overground walking systems understood as independent exoskeletons, wearable robotic *walking devices, stationary devices* - treadmills, exoskeletons integrated with an extensive system for rehabilitation [2]. In the further part of the article, examples of each type will be described.

Overground walking systems

The shape and function of the assisted parts of the human body are taken into account while designing and constructing exoskeletons. Both size and weight of individual elements are taken into account, but also the need to ensure adequate mobility in individual joints (the so-called number of degrees of freedom). Exoskeletons are becoming more and more popular in medicine and new applications are still being introduced. They do not only serve to multiply strength, but they can effectively replace ineffective muscles and entire limbs [18]. Undoubtedly, exoskeletons have a huge impact on reducing the labour-intensiveness and time consumption of individual exercises in the process of rehabilitation, especially those demanding the simultaneous participation of more than one therapist. Due to the additional equipment - all kinds of sensors - they can also enable simultaneous imaging and analysis of the patient's results, which further facilitates the introduction of adjustments in the therapy plan. The increasingly advanced technological solutions used in exoskeletons, allowing for the compensation of nervous system deficits, patient relief and a wide range of adjustment of the control system to the existing pathologies, are not without significance [19, 20].

Despite the numerous advantages, the complicated process of implementing solutions and emergency procedures remains a huge burden, as well as the necessity to properly train the patient and his carers in the field of matching and arming the exoskeleton. Attention should be paid to the aspects of "humanity" in the process of rehabilitation, and thus the risk of dehumanization of medicine. The lack of the human factor, which a direct contact with a physiotherapist is, causes deficits in the psychological aspect of physiotherapy: lack of empathy, lack of motivation building, but also lack of ongoing assessment of the current state of rehabilitation, and lack of immediate specialist response. Limitations related to the software for robot autonomy may have a direct impact on the actual state and subjective perception of patient safety. Exoskeletons used for gait reeducation are mainly HAL and ReWalk, which is proven by the largest number of tests carried out on them [20-22].

In 2001, ReWalk Robotics created the first powered ExWalk exoskeleton, whereas all current projects are designed mainly for people with paraplegia. The ReWalk system uses patented motion detection technology, as well as battery-powered motorized legs, which in turn activate knee and



hip movements. The system is controlled by computers and dedicated software. The ReWalk system allows the user to sit, stand, walk, turn, and climb stairs. It provides two different modes of work: "personal" - used in everyday life and all-day use, and "rehabilitation" - designed for exercise and therapy in the conditions of clinical rehabilitation [22]. ReWalk system has been tested on patients with paraplegia with full spinal cord injury on C7-T12 and T1-T12 sections. Using the exoskeleton, patients were able to walk independently with maintaining a generally symmetrical gait while being supervised by one person [23-25]. The system has a significant potential as a safe orthosis for outpatient treatment for patients with a spinal cord injury at the chest level. In the conducted research, most people have achieved a level of proficiency in walking, similar to the level of a comparable community with limited walking abilities. A high degree of variability of the results was observed in people with much smaller abilities to regain gait efficiency. Part of this variability was explained by the level of injury, but other factors have not been fully identified [26].

Another exoskeleton used for gait re-education, like ReWalk, is HAL. It reads bioelectric signals acquired only from detectors placed on the user's skin and its main feature is to allow the use of much greater force than a human being would be able to use. It has the ability to recognize the movements that the user intends to perform, so that it controls the power needed to make the move. Moreover, when HAL has adequate support for walking, the feeling and thought of the patient" I was able to walk" comes back to the brain. In this way, the brain gradually learns to emit the necessary signals to resume the motion specified by the gait. This solution greatly contributes to enabling disabled people to take their own first step, without using the HAL exoskeleton [22].

Wearable robotic walking devices

Orthoses placed on the patient's body, i.e. orthopaedic devices stabilizing the joints, can be divided into two types: bilateral external and medial single hip joint; in accordance with the position of the hip joint orthosis. A hip-knee-ankle-foot orthosis (HKAFO) was originally used to reconstruct a paraplegic gait. In Western countries, reconstruction of paraplegic gait with a hip-andknee-joint orthosis equipped with a type located on both sides of the hip joint and hard pelvis support, such as hip guidance orthosis (HGO) and reciprocating gait orthosis (RGO) orthosis, were the primarily used solution. HGO and RGO came to be called the "lateral system". In the lateral system, the position gap between the anatomical and orthotic hip joints is small, and the movement of the orthotics during gait is similar to the anatomical movement. After some time, it was found that in RGO, hard pelvis support connecting the hip joints is not rigid enough to achieve good stability while walking. In addition, the very stiff pelvic rim in the HGO limits the torso movement, and the structure of these orthoses makes it difficult to use a wheelchair while wearing them. To solve these problems, a new unique system was created, called the "medial system". It is characterized by a medial single hip joint located between the thighs. The medial system, introduced as Walkabout, had excellent stability while standing and compatibility with a wheelchair. However, it was noticed that there is a gap between the hip orthosis and the anatomical hip joint, which generates a short step problem while walking. This contributed to the elimination of the construction defect and launching a new orthosis - Primewalk [27].

The legitimacy of using this type of orthoses, e.g. in the elderly and disabled, is confirmed by studies proving that WalkAbout provides the patient with a sense of security and stability during



attempts to walk. Out of 65 patients examined, in 17 patients, WalkAbout proved to be the only accepted and effective solution allowing for independent walking. Patients having experience with other ancillary devices only after rehabilitation with the WalkAbout system showed significant progress in the distances covered [28].

There are also comparative studies in the literature between WalkAbout and RGO, which show differences in their use from the point of view of paraplegic patients (in the T9-T12 thoracic segment). After 14 days of using each orthosis, patients made a subjective assessment of each of them in a questionnaire. The results of the tests showed that both subjects showed the same attitude. There was also no significant preference for either of them. From a rehabilitative point of view, it was found that the use of WalkAbout brought more benefits than RGO and vice versa. Importantly the patients mostly decided to use orthoses for therapeutic purposes than their own aims [29]. Additionally, for people with SCI (spinal cord injury) a juxtaposition of comparative tests results was performed including specific values of: energy consumption, step length strength in the use of a given orthosis. The data included an orthosis of the ankle-hip joint (HKAFO), WalkAbout and RGO and showed similar results for each of them. It is also known that gait parameters can be improved by using this type of orthosis in comparison to conventional walking based on e.g. orthotics to stabilize the knee and counteract the drop of the foot. Unfortunately, due to the low level of energy efficiency and low ability to position the body so that the feeling of full control is achieved, these solutions will not be suitable as a replacement for the commonly used wheelchair [30].

Stationary systems

Stationary systems consist of two main elements: a fixed base structure and a movable overground platform (e.g. treadmill or footrest). These systems use patient relief mechanisms - harnesses and straps to help the patient adopt the phases of gait simulated by programmable footrests [12]. Due to the nature of the mobile part of the system, these systems can be divided into *exoskeleton type devices*, e.g. Lokomat, LOPES, Anklebot and *programmable foot end-effector devices*, e.g. G-EO System, Lokohelp, GT [12].

The Lokomat is a robotized gait re-education system combined with a mass and body parameter measuring device and a treadmill [31]. The main elements of the Lokomat are: treadmill, unloading system, orthosis and control and analysis software, thanks to which it is possible to set any parameters of gait - speed, step length, range of movements in the hip and knee joints. During the therapy, the patient puts on an exoskeleton that allows them to walk on the treadmill under unloading conditions. The main difference in comparison to training on the treadmill is that the patient's legs are guided by a robotized device in accordance with the programmed gait pattern. Computer-controlled robot movement guides the patient - walking training is automated. "Gait trainer", in contrast to the treadmill - consists of two footrests placed on two rods, cradles and cranks, which ensure the drive of the entire system. Foot plates symmetrically simulate posture and gait phases [32]. Unlike treadmill training, gait training is automated and supported by an electromechanical solution. Lokomat, ensuring proper walking cycles (limb transfer time, step length, walking speed), prevents the development of pathological compensations and enables learning the correct gait. Its effectiveness in the re-education of gait in patients after brain stroke,



spinal cord injuries, craniocerebral injuries, MPD, MS has been confirmed by numerous scientific studies [33]. In addition to justifying the use of Lokomat for gait re-education, one should remember that thanks to appropriate settings, the patient's effort and effectiveness can be determined. In one of the studies, the energy expenditure of 10 healthy people and 10 patients with hemiparesis were measured. Simulating gait at different speeds, regulating the unloading of one orthosis of the system (in the range of unloading from 60% to 0%), oxygen consumption and heart rate were checked. The final results showed, first of all, that the gait with the use of Lokomat is not passive, i.e. it activates the patient's muscles, forces them to exercise, and thus influences the development and regeneration of the damaged muscles. In addition, increased oxygen intake was noted during the active phase, which is the result of the applied strain. Thus, it was found that the speed of walking does not have an impact on increased oxygen intake. It was also confirmed that the main components of energy consumption are caused by carrying the weight while walking on Lokomat. [34]. The latest reports (2019) regarding the use of the Lokomat device refer to cerebellar ataxia in a 29-year-old patient additionally overburdened with spastic tetraparesis, dysarthria, who until then was able to stand on their own for max. 10 seconds and in everyday life was forced to use a wheelchair. A combination of TDCS (transcranial direct current stimulation) method and virtual reality-based therapy using Lokomat was applied for a few months. Extensive and diverse rehabilitation brought surprising results - a significant improvement in functional results in the ataxia rating scale SARA (related to speech, posture, gait, finger and nose test). Although the study included only one case, it was discovered that the combined neuromodulator-neurorobotic approach could become a promising tool in the rehabilitation of cerebellar ataxia, probably by shaping the plasticity and cerebello-cerebral connection [35].

Another device most often used in patients after stroke or after spinal cord injury is LOPES. The design consists mainly of a hip actuation system, a flexible actuator (placed at the level of the knee) and a treadmill [36]. LOPES affects the walking speed, distance possible to cover, time-space parameters and the range of motion in the hip joint [37]. The main tasks of the device are the possibility to perform the exercises of the hips and legs, support the movements of the pelvis, hips and knees and, of course, gait re-education. LOPES has as many as 8 degrees of freedom, which allows better mobility with fewer disturbances and frictions, and conducting training focused on specific tasks. The device allows for the collection of data which allows for improving independent gait algorithms by comparing different ways of helping patients with neurological dysfunction. An important element of this system is a virtual control model that prevents problems with synchronization as a result of controlling subsequent subtasks in related phases of the gait cycle [38, 39].

A stable tarsus is necessary to maintain the correct posture, safe forward movement and walking. After a stroke or a neurological disorder, foot drop is a frequent impairment of the lower limb caused by weakening of the dorsal flexor muscles responsible for movement and bending of the foot upwards around the ankle. Another complication that can cause lateral instability when walking is the weakening of the ankle inversion operation. This happens when the ligaments of the ankle are excessively stretched sideways, which causes the foot to roll inwards or outwards. These disorders are the result of neurological, muscle or anatomical complications. Anklebot is a robotic



exoskeleton system designed to improve four types of ankle motion: plantar flexion, dorsiflexion, inversion and overturning. During the robotic therapy, Anklebot is fixed to a soft chair and gently attached to the lower limb subjected to therapy with a knee protector and a fitted shoe. Using gamification, Anklebot allows for playing a computer game using the tarsus to move the cursor on the computer screen while the goal-oriented task movement is tracked and recorded. When the lower limb moves in four types of motion, sensors of robotic devices adapt to the ankle muscles, training to perform goal-oriented tasks. During the ankle movement its function and control are improved - the amount of support supplied by the robotic system decreases. This type of therapy makes it possible to achieve the main goal of neurorehabilitation consisting in building strength, engaging muscle memory and stimulating neuro-plasticity [40]. A month-long rehabilitation of patients with brain stroke using the Anklebot system showed evidence of reduction of paresis impairment and the growth of soleus and tibial muscle [41].

One of the most popular systems of rehabilitation and gait re-education in the end-effector technology is the G-EO System. The device consists of elements such as a handrail system, ramp, patient unloading system and movable footrests. The extensive software allows for precise programming of training sessions, current and subsequent analysis of the course of the exercises. The design forces the patient to correct the basis of the body, reduces its weight, which makes it easier to focus on coordination and gait training. The harnesses which allow for one- and two-sided body support force progressive change of load level. The available work modes also include: gait training with simulation (constraint) of the physiological gait pattern, training of selected gait phases and simulation of any movement of the lower limbs. The indications for using the device are, among others: brain stroke, brain damage, Parkinson's disease, children's cerebral palsy, multiple sclerosis [42].

Previous studies conducted on patients with stroke showed a comparable pattern of the activation of lower limb muscles during gait training in simulated conditions of walking on the floor and climbing stairs [43]. One of the studies also describes the load test and incremental strain test with intensity control in the form of climbing stairs, in which the cardio-pulmonary parameters, oxygen uptake and pulse were obtained. The final results brought about significant cardiopulmonary reactions to the generally accepted principles of aerobic training [44].

The gait trainer, called simply Gait Trainer is as common as the G-EO System. Two versions of the device are presently available, while the idea of its functions remains unchanged. It is equipped with two parallel bars to which the patient's feet are fixed, a lift, a harness system and a modern IT system enabling the control of the current stage of therapy. The equipment allows for supporting the learning of the gait pattern and correcting the occurring disorders. During the training, the patient is placed on platforms simulating a road; they have a tailored unloading harness and in the exercise mode, Gait Trainer controls the centre of gravity of the patient in both the coronal and sagittal plane. The characteristic feature of this device is the possibility to considerably limit the physiotherapist's intervention during the training [39, 45].

A series of tests based on gait training and stairs climbing by people after a brain stroke have been performed for the GT electromechanical gait trainer. A series of studies involving a total number of over 2,500 patients have proven that the end-effector therapy is effective in restoring and



improving the ability to walk among people with a broadly defined nervous system damage. A significant role in the use of the GT device is its simplicity of putting on and taking off, lack of risk of knee displacement, and thus - little chance of disturbing the activation pattern of the lower limbs. The patient's sense of safety affected their involvement in the therapy as well as more satisfying results [46].

Conclusions

A wide review of available literature undoubtedly indicated the dynamics and evolution of technological solutions used in medicine. The spectrum of available options means that in the case of any illness resulting in the patient's difficulty with walking or controlling the lower limbs, it is possible to undertake a rehabilitation and re-education attempt. There is also no doubt about the advantages of using devices and robots in the process of treatment. In the case of each group of the possible solutions, the research proved that the combination of conventional therapy with robotic devices gives better results: restoring the gait function, reducing recovery time, increasing the walking speed reached so far, lengthening the pace, improving endurance. The human factor is significantly minimized and provides numerous benefits. Limiting the presence of an increased number of staff contributes not only to the reduction of medical costs, but also allows for the possibility of simultaneous rehabilitation by one physiotherapist. The situation of physiotherapist's fatigue is excluded, and thus it increases one's effectiveness and opportunities to support patients.

The transmission of the gait function pattern plays a very important role. With the use of robots, it is performed over a fixed length of time and in a continuous and repeatable manner. This results in eliminating stressful situations for the patient and therapist, who until now has had to set the lower limb in several regions (hip joint, knee joint, ankle joint) in order to trigger successive gait phases, while observing appropriate guidelines. The extensively developed systems and exoskeletons allow the patient in the rehabilitation process to use strength levels which are adapted to the current stage of therapy - they are appropriately reduced (unloading with tractions, absorption of overloads by exoskeletons) or increasing (resignation from unloading). It can be stated that thanks to the use of robotics, rehabilitation can take a more attractive form than before - the use of virtual reality, games, visualization which allows for distracting the patient's attention from the ailments and directs it to the targeted actions. From the point of view of a sick person, so far sentenced to a life in a wheelchair, dependence on others, lack of perspectives and frequent exclusion from the society, the recovery of fitness becomes real, and prospects for the future are improving.

Despite the intriguing and impressive solutions that bring numerous benefits - mainly for the patient - there is still a lack of research that clearly defines the most effective device for specific diseases [47]. Despite the same diagnosis their functional state of the lower limbs and the scope of existing possibilities and need of support may be different [48]. This generates the necessity of implementing therapies with assumptions whose effects are not fully predictable. According to the authors, it would also be necessary to apply certain guidelines for specific diseases: type of device used, time of therapy, the hierarchy of gait re-education stages. Although these factors are individually matched to patients, published research results still refer to small samples (up to



several dozen patients). The implementation of rehabilitation by various units, and thus medical teams with different treatment concepts, does not support building a pattern which would be the basis for the fastest possible therapeutic success. The costs of using modern equipment and the entire rehabilitation process are still a considerable burden. At the moment, a small percentage of patients with gait dysfunctions or other problematic neurological disorders can afford a medical robot in their place of living and a private visit of a therapist each time.

This study provides an extremely general and partial overview of the available solutions. Undoubtedly, further analysis of this subject will be performed, and further studies will be conducted to introduce the aspects of the applied solutions in the context of a specific disorder. From the point of view of the authors, the most valid point is to solve the issue of the crucial element, implemented at the beginning of therapy in specific diseases. Deciding whether the transfer of the gait pattern, muscle development or strength enhancement is the key issue in the given case seems to be of vital importance from the point of view of starting the rehabilitation process.

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A NON-STANDARD ANALYSIS OF THE SYLVESTER-GALLAI THEOREM

Mariusz Swornóg

Instytut Matematyki, Wydział Matematyczno-Fizyczno-Techniczny, Uniwersytet Pedagogiczny im. KEN, Kraków corresponding author: mariusz.swornog1@student.up.krakow.pl

Abstract:

It is still an open problem in mathematics to find a necessary and sufficient condition for arrangement of lines existence over fixed field. There exist a number of necessary conditions for arrangement existence for some fields. One of this conditions is Sylvester-Gallai theorem for real projective plane $\mathbb{P}^2_{\mathbb{R}}$. There are well-known counterexamples for this thesis over complex and finite projective planes. Therefore it is natural to ask at which projective planes this theorem is also true. At this paper we present a generalisation of the Sylvester-Gallai theorem for projective planes over ordered fields. This is a quite innovatory combination of a non-standard analysis and an algebraic geometry.

Keywords:

algebraic geometry; non-standard analysis; arrangements of lines

An introduction to the arrangements of lines theory

Let $(\mathbb{F}, +, \cdot, 0, 1)$ be an algebraic field. *Projective plane* $\mathbb{P}^2_{\mathbb{F}}$ over algebraic field \mathbb{F} is defined as a quotient structure

$$\mathbb{P}_{\mathbb{F}}^{2} \coloneqq \left(\mathbb{F}^{3} \setminus \{(\mathbf{0}, \mathbf{0}, \mathbf{0})\}\right) / \mathscr{T}, \qquad (1)$$

where $r \in (\mathbb{F}^3 \setminus \{(0, 0, 0)\})^2$ is an equivalence relation given by equivalence

$$(a_1, a_2, a_0) \operatorname{\mathcal{T}}(b_1, b_2, b_0) \Leftrightarrow \operatorname{rank} \begin{bmatrix} a_1 & a_2 & a_0 \\ b_1 & b_2 & b_0 \end{bmatrix} = 1 \text{ over } \mathbb{F}^3(\mathbb{F}).$$
(2)

Equivalence class $[a_1:a_2:a_0] \in \mathbb{P}^2_{\mathbb{F}}$ is a *projective point*. Projective points with $a_0 \neq 0$ can be map onto "normal" (non-projective) plane \mathbb{F}^2 by

$$[a_1:a_2:a_0] = [a_1a_0^{-1}:a_2a_0^{-1}:\mathbf{1}] \mapsto (a_1a_0^{-1},a_2a_0^{-1}).$$
(3)

Classes $[a_1:a_2:0]$ cannot be map into \mathbb{F}^2 . That are so-called *points at infinity*. Therefore there is a mapping

$$\mathbb{P}_{\mathbb{F}}^2 \cong \mathbb{F}^2 \cup \left\{ \left[a_1 : a_2 : \mathbf{0} \right] \mid (a_1, a_2) \in \mathbb{F}^2 \setminus \left\{ (\mathbf{0}, \mathbf{0}) \right\} \right\}.$$

$$\tag{4}$$

Some special groups of projective points create the *projective lines* (called also \mathbb{F} -*lines*). Projective line ℓ is defined as

$$\boldsymbol{\ell} \coloneqq \Pi(\boldsymbol{\mathcal{V}} \setminus \{(\boldsymbol{0}, \boldsymbol{0}, \boldsymbol{0})\}), \tag{5}$$



where $\Pi: \mathbb{F}^3 \setminus \{(0,0,0)\} \ni (a_1,a_2,a_0) \mapsto [a_1:a_2:a_0] \in \mathbb{P}_{\mathbb{F}}^2$ and \mathcal{V} is a two-dimensional vector subspace of vector space $\mathbb{F}^3(\mathbb{F})$. A fundamental property of the projective planes is that every pair of distinct lines meets in exactly one point.

Proof. Let $\ell_1 := \Pi(V_1 \setminus \{(0, 0, 0)\} \text{ and } \ell_2 := \Pi(V_2 \setminus \{(0, 0, 0)\} \text{ be two projective lines with } V_1 \neq V_2$. Let $V_1 + V_2 := \{\beta_1 a_1 + \beta_2 a_2 \mid (a_1, a_2) \in V_1 \times V_2 \land (\beta_1, \beta_2) \in \mathbb{F}^2\}$. We know that:

$$\begin{cases} \dim V_1 = 2\\ \dim V_2 = 2\\ \dim(V_1 + V_2) = \dim V_1 + \dim V_2 - \dim(V_1 \cap V_2) \\ \dim(V_1 + V_2) \le 3\\ V_1 \neq V_2 \end{cases}$$
(6)

Therefore dim $(V_1 \cap V_2) = 1$, hence $\exists_{x \in V_1 \cap V_2} x \neq (0, 0, 0)$. Let us fix that x. Therefore $x \in V_1 \cap V_2 \setminus \{(0, 0, 0)\}$, so $x \in V_1 \setminus \{(0, 0, 0)\}$ and $x \in V_2 \setminus \{(0, 0, 0)\}$. That means $\Pi(x) \in \ell_1$ and $\Pi(x) \in \ell_2$. Therefore $\ell_1 \cap \ell_2 \neq \emptyset$. Let us suppose that exists $y \neq x$ and $y \in \ell_1 \cap \ell_2$. That means $\exists_{x \in \mathbb{F}^3 \setminus \{(0,0,0)\}} y = [z]$. Therefore $\exists_{k_1 \in V_1} \Pi(z) = \Pi(k_1)$ and $\exists_{k_2 \in V_2} \Pi(z) = \Pi(k_2)$, hence $\exists_{\xi_1 \in \mathbb{F}} z = \xi_1 k_1$ and $\exists_{\xi_2 \in \mathbb{F}} z = \xi_2 k_2$. That implies $z \in V_1 \cap V_2$. It is true that $\exists_{\psi \in \mathbb{F} \setminus \{0\}} z = \psi x$, because vector x is basis of vector space $V_1 \cap V_2$. Hence y = x.

Therefore at any projective plane do not exist parallel projective lines.

The set of all points at infinity is also a projective line and it is given by two-dimensional vector space $\mathbb{F}^2 \times \{0\}$. We denote

$$\ell_{\infty} \coloneqq \Pi(\mathbb{F}^2 \times \{\mathbf{0}\}). \tag{7}$$

Arrangement of lines \mathfrak{L} is a family of a finite number of \mathbb{F} -lines at $\mathbb{P}^2_{\mathbb{F}}$. Set $\mathcal{P}(\mathfrak{L})$ is a set of all intersection points. In one point can met two or more lines. *Multiplicity* m(P) of point P is number of lines that met in that point. Let

$$t_k := \#\{P \in \mathcal{P}(\mathfrak{L}) \mid m(P) = k\}, \text{ for } k \in \{2, 3, \dots\}.$$
(8)

A point with multiplicity 2 is called an *ordinary point*. Every arrangement of lines satisfies the condition below:

$$\binom{d}{2} = \sum_{k=2}^{\infty} \binom{k}{2} t_k \tag{9}$$

where d is a number of lines in arrangement. That is a purely combinatorial condition. At the lefthand side of this equality is the maximal number of ordinary points that can be create by arrangement of d lines. At the right-hand side of equality (9) is the sum of maximal numbers of ordinary points that can be created from every point with multiplicity k created by \mathfrak{L} . Because of non-existence of parallel lines at projective plane there is equality (9) instead of the non-strict inequality.

We can look at equality (9) in the other way. It can be a Diophantine equation over natural numbers. Solutions of equation (9) with fixed parameter d give us every possible arrangement of d projective lines re-created from sets of points with multiplicity $(\mathcal{P}(\mathfrak{L}), m)$. We denote these solutions as $(t_2, t_3, t_4, \dots, t_d)$.



For d = 2 there is only one solution of equation (9) $-t_2 = 1$. That are just any two lines at projective plane.

For d = 3 there are two solutions: (0,1) and (3,0). The first one is a pencil of three lines. The second one is a triangle.

For d = 4 there are four solutions: (0,0,1), (0,2,0), (3,1,0), (6,0,0).



Fig. 1. Arrangements (0,0,1), (3,1,0) and (6,0,0). Source: own work

Solution (0,0,1) gives us a pencil, (3,1,0) – quasi-pencil, (6,0,0) – star configuration. But solution (0,2,0) cannot be realized at any projective plane. That causes a problem – not every solution of (9) can be realized geometrically. The problem is even bigger – we do not have a condition to check if given solution can be realized geometrically. It is still an open problem in mathematics to create a necessary and sufficient condition for arrangement existence. And some solutions can be realized only over some specific fields. For example – let us look at solutions of (9) for d = 7.

	t_2	<i>t</i> ₃	t_4	t_5	<i>t</i> 6	<i>t</i> ₇	Existence over $\mathbb{P}^2_{\mathbb{R}}$
S01	0	0	0	0	0	1	exists
S02	0	0	1	0	1	0	does not exist
S03	0	2	0	0	1	0	does not exist
S04	3	1	0	0	1	0	does not exist
S05	6	0	0	0	1	0	exists
S06	1	0	0	2	0	0	does not exist
S07	2	1	1	1	0	0	does not exist
S08	5	0	1	1	0	0	does not exist
S09	2	3	0	1	0	0	does not exist
S10	5	2	0	1	0	0	does not exist
S11	8	1	0	1	0	0	exists
S12	11	0	0	1	0	0	exists
S13	0	1	3	0	0	0	does not exist
S14	3	0	3	0	0	0	does not exist
S15	0	3	2	0	0	0	does not exist
S16	3	2	2	0	0	0	does not exist
S17	6	1	2	0	0	0	does not exist
S18	9	0	2	0	0	0	exists
S19	0	5	1	0	0	0	does not exist
S20	3	4	1	0	0	0	does not exist
S21	6	3	1	0	0	0	exists
S22	9	2	1	0	0	0	exists
S23	12	1	1	0	0	0	exists
S24	15	0	1	0	0	0	exists
S25	0	7	0	0	0	0	does not exist
S26	3	6	0	0	0	0	exists
S27	6	5	0	0	0	0	exists

Tab. 1. Solutions of Diophantine equation (9) for d = 7

S28	9	4	0	0	0	0	exists
S29	12	3	0	0	0	0	exists
S30	15	2	0	0	0	0	exists
S31	18	1	0	0	0	0	exists
S32	21	0	0	0	0	0	exists

Source: own work, [1]

As we can see, half of the solutions for 7 lines cannot be realized at real projective plane (for more details consult [1]). That is a big problem to determine if given solution can be realized geometrically over some field. For example, solution S26 is not an arrangement over $\mathbb{P}^2_{\mathbb{R}}$. There is exactly one plane that realizes this arrangement – Fano plane $\mathbb{P}^2_{\mathbb{F}_2}$ (for more details consult [2]). This arrangement of \mathbb{F}_2 -lines is called *Fano configuration*.



A necessary and sufficient condition for arrangement existence is not created yet. But there exist some necessary conditions. One of them is the Sylvester-Gallai theorem.

A brief look at the Sylvester-Gallai theorem

In 1821 John Jackson wrote *Rational amusement for winter evenings* ([3]). One of the puzzles was to plant 9 trees that in each row there will be at least three trees. Trivial solution is to plant all trees in one row. But finding non-trivial solutions was ineffective. In 1893 English mathematician James J. Sylvester posed it as a geometrical problem ([4]). He asked if is it possible to non-collinearly arrange n points at the real plane that at every line span by two points exists third point. It was negatively solved in 1933 by Hungarian mathematician Tibor Gallai.



The Book of Articles National Scientific Conference "Science and Young Researchers" III edition June 15, 2019, Łódź



Fig. 3. James J. Sylvester Source: public domain

Sylvester-Gallai theorem

Every non-collinear configuration of points at real projective plane $\mathbb{P}^2_{\mathbb{R}}$ span a line that includes exactly two points from this configuration.

As we can see, original Sylvester-Gallai theorem is about points, not lines. But at the projective planes is so-called *principle of projective plane duality*. It is a theorem that says that theorems are equivalent if we interchange "points" \leftrightarrow "lines", "lies on" \leftrightarrow "intersects at" and "belong to a pencil" \leftrightarrow "are collinear". The principle of projective plane duality gives the dual Sylvester-Gallai theorem, which is more interesting from our point of view.

Dual Sylvester-Gallai theorem

Every non-pencil arrangement of lines at real projective plane $\mathbb{P}^2_{\mathbb{R}}$ generates an ordinary point.

Therefore, if solution of Diophantine equation (9) has $t_2 = 0$ and is not (0,0,...,0,1), then it cannot be realized geometrically at real projective plane. It is natural to ask if this theorem is true over any projective plane. It is not. There are well-known counterexamples for this thesis over complex and finite projective planes. For complex projective plane $\mathbb{P}^2_{\mathbb{C}}$ we have so-called *dual Hesse configuration* for 9 \mathbb{C} -lines with 12 triple-points and no ordinary points, and for finite projective planes we have Fano configuration for 7 \mathbb{F}_2 -lines with 7 triple-points and no ordinary points. For more details consult [5]. So at which planes this theorem is valid and how to proof that?





Fig. 4. Dual Hesse configuration (left) and Fano configuration (right) Source: own work

In the history of mathematics there were discovered many proofs of Sylvester-Gallai theorem. Tibor's proof was the first one, but it was quite complicated and now it is almost forgotten. These days the most popular is proof that was made by American mathematician Leroy Milton Kelly. It is so popular due to its simplicity, shortness and intuitional implications. But Kelly's proof is very hard to generalize into more abstract structures. This proof is based on metric properties and also requires angles measure, congruence of triangles etc. Those properties cannot be directly generalized to ordered geometry, they need some more axioms. For our purposes the best choice is quite forgotten Melchior's proof ([6]). Melchior's proof is based on a graph theory, that is easy to generalize into the ordered fields theory. Modern interpretation of this proof can be found at [2]. For some other necessary conditions for arrangement of lines existence consult [7] (a review of some basic results) and [8] (the advanced modern results).

The ordered fields theory

The concept of ordered fields comes from David Hilbert, the great German mathematician. Standard algebra gives us some extension fields of \mathbb{R} , like for example \mathbb{C} . But those extensions are in some way very different from field of real numbers. Structure \mathbb{R} can be totally ordered. Structure \mathbb{C} – cannot.

Definition: Ordered field

Structure $(\mathbb{F}, +, \cdot, \mathbf{0}, \mathbf{1}, \leq)$ is an ordered field iff $(\mathbb{F}, +, \cdot, \mathbf{0}, \mathbf{1})$ is an algebraic field, (\mathbb{F}, \leq) is a totally ordered set, $\forall_{a,b,c,d\in\mathbb{F}} a \leq b \land c \leq d \implies a+b \leq c+d,$ $\forall_{a,b,c\in\mathbb{F}} a \leq b \land \mathbf{0} \leq c \implies a \cdot c \leq b \cdot c.$

The ordered fields have a lot of interesting properties. For example, in every ordered field

0 ≼ 1.

(10)



Proof. Let be given $k \in \mathbb{F}$. Due to the total order, there are two options: $\mathbf{0} \leq k$ or $k \leq \mathbf{0}$. In the first case $\mathbf{0} \leq k \cdot k$ (due to the compatibility with multiplication). If $k \leq \mathbf{0}$, then $\mathbf{0} \leq -k$ (due to the compatibility with addition), hence $\mathbf{0} \leq (-k) \cdot (-k)$ (due to the compatibility with multiplication), therefore $\mathbf{0} \leq k \cdot k$ (due to the purely algebraic reasons). Now we know that $\forall_{k \in \mathbb{F}} \mathbf{0} \leq k^2$. We also know that in every field $\mathbf{1} \cdot \mathbf{1} = \mathbf{1}$ (due to the definition of neutral element). Therefore $\mathbf{0} \leq \mathbf{1}$.

Let us look at the finite fields. Because of the compatibility with addition we have

$$\leq \mathbf{1} \leq \mathbf{1} + \mathbf{1} \leq \mathbf{1} + \mathbf{1} + \mathbf{1} \leq \dots \leq \mathbf{n} \leq \dots$$
(11)

Over the finite fields in some point there is $\mathbf{0} = \mathbf{1}$ and this is a contradiction, because $\mathbf{0} \neq \mathbf{1}$. Let us suppose that there is given finite field \mathbb{F} that $\#\mathbb{F} = n$. After *n* iterations (look at (11)) we used all of the elements. But we still can add one more. So we have

$$n \leq n+1, \tag{12}$$

but n + 1 cannot be any new element, hence 0 = 1 and it cannot be true. For example, let us consider (\mathbb{F}_5 , $+_5$, \cdot_5 , 0, 1). Then

$$\mathbf{0} \leqslant \mathbf{1} \leqslant \mathbf{2} \leqslant \mathbf{3} \leqslant \mathbf{4} \leqslant \mathbf{0} \tag{13}$$

and this is a contradiction. Therefore any finite field is not the ordered field.

Let us look at the complex numbers \mathbb{C} . We know that $i^2 = -1$. If \mathbb{C} would be an ordered field, then $0 \leq i^2$. That means $0 \leq -1$ and due to compatibility with addiction $1 \leq 0$, hence 0 = 1 and this is a contradiction. Therefore the field of the complex numbers cannot be an ordered field. For more details about the ordered fields theory consult [9] and [10].

The non-standard analysis propose a number of the ordered extensions of \mathbb{R} . One of the most noticeable examples is an ordered field of *hyperreal numbers* ($\mathbb{R}^*, \bigoplus, \odot, 0^*, 1^*, \leq$). We present its construction below.

A family $F \subset \mathcal{P}(\mathbb{N})$ is a *filter* on \mathbb{N} iff $\emptyset \notin F$, $\forall_{A,B \in F} A \cap B \in F$,

 $\forall_{A,B\subset\mathbb{N}}\;A\in F\wedge A\subset B\implies B\in F.$

If filter F satisfies also condition

$$\forall_{A \subseteq \mathbb{N}} A \in F \lor \mathbb{N} \setminus A \in F \tag{14}$$

it is called an ultrafilter.

Family $\mathcal{F} \coloneqq \{A \in p(\mathbb{N}) \mid \#(\mathbb{N} \setminus A) < \infty\}$ is called a *Fréchet filter*. The Fréchet filter is not an ultrafilter. Although, by Zorn's lemma it can be extended to ultrafilter \mathfrak{U} .

Let us define a relation $\equiv \in (\mathbb{R}^{\mathbb{N}}) \times (\mathbb{R}^{\mathbb{N}})$ as

$$(a_n) \equiv (b_n) \Leftrightarrow \{n \in \mathbb{N} \mid a_n = b_n\} \in \mathfrak{U}. \tag{15}$$

Relation (15) is an equivalence relation. We define hyperreals as a quotient structure $\mathbb{R}^* := \mathbb{R}^{\mathbb{N}} / \equiv$. The algebraic operations and the total order are defined as:

$$[(a_n)] \oplus [(b_n)] \coloneqq [(a_n + b_n)], \tag{16}$$

$$[(a_n)] \odot [(b_n)] \coloneqq [(a_n \cdot b_n)], \tag{17}$$

$$[(a_n)] \leq [(b_n)] : \Leftrightarrow \{n \in \mathbb{N} \mid a_n \le b_n\} \in \mathfrak{U} . \tag{18}$$

For more details about the hyperreal numbers consult [10].



The non-standard generalization of the Sylvester-Gallai theorem

Let \mathbb{P}^2_{\leq} be a projective plane over ordered field $(\mathbb{F}, +, \cdot, 0, 1, \leq)$. At totally ordered projective planes points lying on the line divides it onto sections called *edges*. The reason for that is order \leq , which indicates the left and the right side of line. At these planes edges indicates spaces between them, called *faces*. Therefore, over totally ordered plane we can define so-called *Euler-Poincaré characteristic*. Euler-Poincaré characteristic is a number

$$\chi \coloneqq v - e + f \,, \tag{19}$$

where v is the number of intersection points (*vertices*), e is the number of edges and f is the number of faces. For finite, planar, connected graphs $\chi = 2$. Projective arrangements of lines at \mathbb{P}^2_{\leq} are in some way similar to these graphs. The difference is that arrangements of lines do not have external face. That is why for arrangements of lines that are not a pencil we have $\chi = 1$. We present an example below.



Fig. 5. Faces and edges at ordered projective plane Source: own work

As we can see, we have an arrangement of 3 lines at \mathbb{P}^2_{\leq} . For this arrangement we have 4 faces (F₁, F₂, F₃, F₄), 6 edges (E₁, ..., E₆) and 3 vertices (grey dots). Hence $\chi = 3 - 6 + 4 = 1$.

This analogy between ordered arrangements of lines and planar, connected graphs is crucial. And as we can see, we are using any ordered projective plane \mathbb{P}^2_{\leq} . It does not have to be real projective plan. It could be hyperreal projective plane or any other projective plane over any even non-Archimedean ordered extension of field of real numbers \mathbb{R} . That leads as to desirable generalization.





Fig. 6. Leonhard Euler (1707-1783) Source: public domain



Fig. 7. Henri Poincaré (1854-1912) Source: public domain

Generalization of the Sylvester-Gallai theorem

Every non-pencil arrangement of lines at ordered projective plane \mathbb{P}^2_{\leq} indicates an ordinary point.

Proof. Let be given fixed arrangement of \mathbb{F} -lines at ordered projective plane \mathbb{P}^2_{\leq} that is not a pencil. That means the number of lines is $d \geq 3$ and $t_d = 0$. That implies $v \geq 3$ and every face is bounded by at least 3 edges, hence

$$f \le \frac{2}{3}e . \tag{20}$$

Due to Euler-Poincaré characteristic of ordered projective plane we have

$$f = 1 - v + e . \tag{21}$$

Inequality (20) and equality (21) gives

$$e \le 3v - 3. \tag{22}$$

Let us assume that every vertex meets at least 6 edges. Therefore

$$3v \le e$$
. (23)

But due to (22) we have

$$3v \le 3v - 3 \tag{24}$$

and this is a contradiction. Therefore there exists at least one vertex that meets 5 edges or less, hence there exists at least one ordinary point. ■

Therefore at any projective plane over ordered field arrangements with $t_2 = 0$ that are not a pencil cannot be realized. These fields can be for example field of real numbers, field of hyperreal numbers, Levi-Civita field, field of surreal numbers etc.

There are also other benefits from this generalization. Some stronger results then the Sylvester-Gallai theorem are based on exactly the same proof – on the Euler-Poincaré characteristic. And they can be generalized in the same way too. We present these two theorems below.

Melchior's inequality ([6])

Let be given arrangement of lines \mathcal{L} at $\mathbb{P}^2_{\mathbb{R}}$ that is not a pencil. Then



$$\sum_{k=2}^{\infty} (k-3)t_k \le -3.$$

Generalized Melchior's inequality ([1])

Let be given arrangement of lines \mathcal{L} at $\mathbb{P}^2_{\mathbb{R}}$ that is not a pencil. Let *n* be fixed natural number. Then

$$\sum_{k=2n+1}^{\infty} (k - (2n+1))t_k + 2n + 1 \le \sum_{k=2}^{2n} (2n+1-k) t_k.$$

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PREPARATION OF BIOPOLYAMIDE COMPOSITES AND THEIR APPLICATION

Mieczysław Zaczyk

Katedra Towaroznawstwa Żywności, Wydział Towaroznawstwa i Zarządzania Produktem, Kraków corresponding author: m.zaczyk@outlook.com

Abstract:

The article presents data on the properties of polyamides, including biopolyamides, as well as information from recent years on composites based (mainly) on biodegradable polymers, supported by information from the biopolymer market, conclusions from research related to biodegradation under natural conditions, alone, allowing for the formulation of certain conclusions, as well as forecasting the future in the use of composites in various areas of life and industry.

Keywords:

polyamides, biopolyamide composites, biocomposites, biodegradability

Introduction

The term "biocomposites" is quite broad and refers to composites where at least one of the components is "bio". These will be either petrochemical polymers or biopolymers filled with natural fibers as well as biopolymers with synthetic fibers [1]. The biopolymers themselves must meet at least one of two requirements - be biodegradable or come from renewable sources. We are currently observing the unusually rapid development of biocomposites appearing in more and more recent sectors of the economy, such as the automotive, packaging, construction and many other industries. Development drives growth: thanks to a large number of studies, publications and implementations, the techniques of producing biocomposites are constantly being improved, and their production is becoming more and more profitable every year [1].

Biopolymers on the market

Biopolymers which are currently available on the market currently account for approx. 5-10% of the world production of polymer materials [2]. Biodegradable polymers are a group of materials that currently attracts great interest from scientists and industry representatives due to the search for alternative sources for petrochemical raw materials and environmentally friendly materials that decompose under ambient conditions and can be recycled via composting.

An important group among bio-based materials are polymers obtained from biofuels. Already in the early 1970s in India, there were made first attempts were made to convert bioethanol into ethylene for the production of polyethylene, poly (vinyl chloride) and styrene. In the 1980s, around



150,000 tons of bioethanol were produced in Brazil annually, then processed into polyethylene and poly (vinyl chloride) [3].

In the early 1990s, production was suspended, but in 2010 Braskem re-launched it on a large scale (200,000 tonnes of "green" polyethylene per year). Thus, Braskem became the leading producer of biopolymers in the world.

The increased production of biopolymers is associated with the growing consumer awareness, especially a trend for the so-called "green packaging". Polymers are produced from natural renewable sources, such as plants. They play an important role in reducing CO2 emissions. What is more, they are potentially the most ecological material for packaging production, and after appropriate modification can be used in composites with the properties of construction materials. However, their introduction on the market is associated with limitations, among which are the relatively high production costs, worse production efficiency of biomass-based materials and poorer physico-mechanical properties which are significant compared to polymers based on petrochemical raw materials [4].

Biopolyamides available on the market do not have their petrochemical counterparts. And although they may be similar in some properties to traditional polyamides, they are completely different materials. Currently produced biobased polyamides are made of long carbon chains. They have many advantages – chemical resistance, flexibility, low density, low absorbability, high vibration damping ability. However, they have worse mechanical properties than traditional plastics used as engineering materials (including polyamide 6), which limits their use as construction materials. The introduction of fillers, even in small amounts, can significantly improve the strength and rigidity of the material, while retaining the many advantages that the biopolyamide matrix provides.

The production of composites based on thermoplastic polymers with vegetable fibers also requires consideration of many factors concerning fillers: length, type and structure of fiber, lignin content, and first of all adhesion of fiber and polymer, which determine its subsequent mechanical properties [5].

Chemically, natural fibers consist mainly of cellulose, hemicelluloses, lignins and pectins, and contain some amounts of water and waxes [6]. Materials in which both the matrix and fillers are biodegradable and obtained from natural raw materials constitute one of the most interesting, though not very popular, groups of biocomposites [7].

The technical use of pure biopolymers is still very limited due to their usually inferior mechanical and thermal properties compared to traditional materials, especially in relation to their price [8]. On the other hand, the introduction of natural fillers into biopolymers results in improved properties and often cost reduction, while on the other, advantages such as the total bio-efficiency of the material and the possibility of its composting or easy combustion with energy recovery are preserved. Additionally, it is possible to control the time of biodegradation by selecting the type and amount of natural fibers or mineral particles.

Another advantage of biopolymers conducive to the formation of their composites with natural fibers is their low softening temperature (160-190°C). The degradation temperature of vegetable fibers is usually from 190-220°C, which greatly limits the possibility of introducing them to


traditional petrochemicals. Requiring usually higher processing temperatures. In addition, both biodegradable polymers and natural fillers are hydrophilic in nature, and in some cases they also have a chemical similarity. It can facilitate the creation of permanent bonds, the filler and reduce the need for expensive chemical modifications [8].

Biopolymers obtained from biomass

Biopolymers obtained from biomass can be used as matrices of composites filled with both natural fibers as well as synthetic ones or mineral particles. These polymers are not biodegradable and therefore the addition of fillers such as glass or carbon fibers does not eliminate their "ecological advantages". On the other hand, the introduction of natural fibers makes it possible to obtain a completely biogenic derivative. Processing temperatures of the biopolymers in question allow them to be processed with natural fibers below the degradation temperatures of the fillers.

The influence of polymer biocomposites on the environment (their biodegradability)

Polymeric biocomposites are materials with high application potential, high potential, indicated as those whose dissemination can contribute to reducing our ecological footprint. Currently, the most popular products for plastic products are composites with natural fibers with a traditional (petrochemical, non-biodegradable) matrix. Biodegradable or non-biodegradable biocomposites, but bio-derivatives, are still not much developed.

Some biocomposites and their components obtained from biomass are still unfortunately relatively expensive materials due to the still small scale of production, the often occurring need for chemical or physical modification of fibers or warp, as well as the need to provide energy, water, fertilizers and possibly stable conditions for the growth of raw materials. This applies mainly to biopolymers: polyhydroxyalkanoates, biopolyamides and thermally resistant polylactides. Nevertheless, their research, processing, application is becoming more and more profitable [8].

Some consumers are ready to pay more for a product advertised as environmentally friendly. Also due to the increasingly stringent restrictions on CO2 emissions, partial substitution of petrochemical raw materials in renewable production processes brings profits. This makes a special sense in agricultural countries with large biomass resources and biofuel production capacities. Knowing the current limitations of materials obtained from renewable raw materials, wisely choosing them in terms of specific applications and skillfully advertising them, one can already obtain benefits [9].

The future of biocomposites in Poland and in the world

The use of polymer biocomposites made from renewable raw materials is becoming increasingly common in conditions of growing biotechnology. Today, there is a growing interest in these materials in the automotive and aviation market as well as in the medical industry and rehabilitation equipment.



In Poland, the biocomposite market, which has huge potential, is still undeveloped. However, currently it begins to develop mainly in the United States, Germany and Japan. Commercial production of this type of composites with a high modulus of elasticity, good strength, having the ability to dissipate energy and other interesting properties is already underway. Both granules and finished products are available. The most interesting group of plastics and composites, and at the same time the most promising are those based on starch and polylactide, already produced on a large scale and relatively well-known [10].

An example of already implemented materials can be composites: Kareline PLMS (polylactide with wood fibers) from Kareline and Fibrolon (WPC composite - one of the polylactide types is one matrix) proposed by FKuR. Both composites are designed for various types of applications, such as: panels, profiles, car interiors, various types of injection molded parts, dishes and even coffins and urns. The polylactide kenafem composites were introduced a few years ago in the parts of the computer and the cover of the mobile phone (FOMA N701i ECO) from NEC [11].

Toyota also used polylactide filled with kenafem in some models of its cars (Raum and Prius), in a spare wheel cover. Other car companies, such as Ford, Honda, Mazda, also research, develop and use new bioplastics and biocomposites in the interiors of their cars. An interesting example may be wood-like polyhydroxybutyrate (PHB) composites filled with hemp fibers, used as a wood substitute, for example in furniture or floors.

In Germany, such companies as Holstein-Flachs, Linotech, Tecnaro, Gehr and several others have in their offer granulates of biocomposites or ready biodegradable products of various types: from furniture, containers, toys to biodegradable pots and urns. The enormous development of technologies and the increased competitiveness of bioplastics in recent years allow the display of a wider and wider range of products, and at the same time open to more and more opportunities [10].

Today, the increase in the amount of waste is a significant problem for the modern, fastgrowing world. New legal regulations are introduced to guarantee the production of environmentally friendly materials. New products are promoted that can be recycled or naturally biodegraded. An important argument here is the possibility of much easier subsequent thermal utilization by burning them with energy recovery. All these criteria are met by biocomposites, in other words, materials in which at least one component is of natural origin.

In the coming years, it is highly probable that polymer composites with the addition of natural fibers will be reused in many areas of our lives. Currently, they are already used as elements of products in many industry sectors, including automotive, electromechanical and aerospace industries. It is estimated that in the near future, 20-30% of world production of fiberglass products will be replaced with natural fiber comos [11].

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