Załącznik IIA (Appendix IIA)

Summary of professional accomplishments
Description of scientific output and accomplishments

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TABLE OF CONTENTS

1. PERSONAL DATA

Name and surname: **Sławomir Obidziński**

Place of employment:

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Department of Agricultural, Food and Forestry Engineering
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2. DIPLOMAS, DEGREES – WITH THE NAME, PLACE AND YEAR OF ACQUISITION AND THE TITLE OF DOCTORAL DISSERTATION:

a) Master of Science, Engineer, field of study: mechanics and mechanical engineering, Białystok University of Technology, Faculty of Mechanics, 16.07.1997, topic of master's thesis: *„Study of heat of phase transitions of selected food products using the differential scanning calorimetry method on the UNIPAN 608 calorimeter"*.

b) PhD in technology, in the field of construction and maintenance of machines, specialty: machines of the food and agricultural industry, The Scientific Council of the Faculty of Mechanical Engineering, 29.03.2006, topic of doctoral dissertation: *„Pelleting of plant materials in a ring working system of a pellet mill"*, supervisor: prof. dr hab. inż. Roman Hejft.

3. ACADEMIC CAREER:

01.10.1997 - 31.03.2006 - assistant lecturer, Białystok University of Technology, Faculty of Mechanical Engineering, Department of Food Industry Machines and Appliances,

01.04.2006 - 31.12.2013 - assistant professor, Białystok University of Technology, Faculty of Mechanical Engineering,
- 01.04.2006 - 30.09.2006 - Department of Food Industry Machines and Appliances,
- 01.10.2006 - 30.09.2008 - Department of Heat Technology and Agricultural Engineering,
- 01.10.2008 - 31.12.2013 - Department of Agricultural and Food Techniques,

since 01.01.2014 - assistant professor, Białystok University of Technology, Faculty of Civil and Environmental Engineering, Department of Agricultural, Food and Forestry Engineering

since 01.09.2008 - senior lecturer, Higher Vocational School in Suwałki,
- 01.09.2008 - 30.09.2012 - Institute of Technology and Life Sciences,
- since 01.10.2011 - Institute of Technology.

4. INDICATION OF ACHIEVEMENT UNDER ART. 16 PARAGRAPH 2 OF THE ACT OF 14 MARCH 2003 ON ACADEMIC DEGREES AND TITLES AND ART DEGREES AND TITLES (DZ. USTAW [JOURNAL OF LAWS] NRO. 65, POS. 595, AS AMENDED: DZ. USTAW OF 2005 NO. 164, POS. 1365, AND DZ. U. OF 2001 NO. 84, POS. 455):

4.1. DESCRIPTION OF ACHIEVEMENT

a) title of scientific/art achievement

„PRESSURE AGGLOMERATION OF FOOD AND AND AGRICULTURAL WASTE MATERIALS"

which documents a monograph series published after the applicant had been awarded the doctoral degree.

b) list of articles documenting the scientific achievement:

1. **Obidziński S. (2011).** Tests of the densification process of tobacco waste. Inżynieria i Aparatura Chemiczna No. 1, 50(42), 29-30. MNiSW=6.
2. **Obidziński S. (2012).** Pelletization process of postproduction plant waste. International Agrophisics. Vol. 26(3), 279-284. (JCR), IF=1.574, MNiSW=20.
3. **Obidzinski S. (2012).** Analysis of usability of potato pulp as solid fuel. Fuel Processing Technology 94(2012), 67–74. (JCR), IF=2.945, MNiSW=32.
4. **Obidzinski S. (2013).** Assessment of the process of production of heating pellets from oat bran with a potato pulp content. Acta Agrophysica, Vol. 20(2), 389-402. ISSN 1234-4125. MNiSW=7.
5. **Obidzinski S. (2014).** Pelletisation of biomass waste with potato pulp content. International Agrophisics. Vol. 28(1), 85-91. (JCR), IF=1.142, MNiSW=25.
6. **Obidzinski S. (2014).** Utilization of post-production waste of potato pulp and buckwheat hulls in the form of pellets. Polish Journal of Environmental Studies. 2014, Vol. 23, No. 4 (2014), 1391-1395. JCR), IF=0.600. MNiSW=15.

The total *Impact Factor* of these articles according to the JCR list is **6.361.**

The character of the papers presented as the scientific achievement is both of the **cognitive** and **application** nature, as they present the influence of material, process, and construction factors on the course of the process of agglomeration of waste plant materials (post-production waste from the food and agricultural industry) and the quality of the obtained product (pellets). They also present guidelines for a new technology for the production of (heating or fodder) pellets from these materials. The research conducted during the preparation of these papers resulted in two patent applications:

1. **Obidziński S., Skwierzyński D.:** Technology for the production of heating pellets from potato pulp. Patent application P.394547 dated 14.04.2011. The Patent Office of the Republic of Poland. Warsaw 2011.
2. **Obidziński S.:** Heating pellets and the technology of their production. Patent application P.398399 dated 12.03.2012. The Patent Office of the Republic of Poland. Warsaw 2012.

which present the new technology for the production of heating and fodder pellets from the studied waste materials, i.e. potato pulp **(in the case of application no. 1)** and a mixture of pulp with other plant materials **(in the case of application no. 2)**. The technologies presented in patent applications no. 1 and no. 2 allow to use potato pulp as a material for the production of a heating fuel in the form of pellets or briquettes.

In the case of each of these publications, as well as in the case of the listed patent applications, I was the main author of the concepts of the conducted research, which I planned and performed, analyzed the results, and then prepared the publications; I was also the main participant in the preparation of the patent applications.

The articles published in JCR indexed journals **(papers no. 2 and no. 3)** have so far been cited 7 times in international scientific literature (i.e. in articles from the Philadelphia list).

c) discussion of research/artistic aims of the above-mentioned publication(s) and the achieved results with discussion on its/their possible use

4.2. INTRODUCTION

According to the data provided by Statistical Yearbook of Industry [2012], 123,500,000 tons of waste was produced in Poland in 2011, including 115,800,000 Mg (93.7%) of industrial waste. Agriculture and the food and agricultural industry (PRS) in Poland generate yearly over 10,000,000 tons of waste that is utilized [GUS 2010; Daniel et al. 2012]. However, according to Daniel and his colleagues [Daniel et al. 2012], the problem of inadequate utilization of waste has become more and more prevalent.

Uncontrolled decomposition of waste from agriculture and the food and agricultural industry (PRS) results in high amounts of pollution being generated, including dangerous compounds and substances. Currently, designing new, rational systems for the processing of waste from food production and processing is a necessity [Arvanitoyannis et al. 2008, Listwan 2009].

EU's approach to waste utilization is based on the following three rules: preventing production of waste, recycling and reusing of waste, and facilitation of ultimate waste disposal and monitoring. The current ecological policy of Poland and the 2014 National Waste Management Plan for the years to come are also compatible with these EU guidelines [Monitor Polski 2010]:

- maintaining the tendency to separate the increase in the amount of produced waste from the increase in economic growth expressed in GDP;
- increasing the proportion of recycling, especially recycling of energy from waste, consistent with the requirements of environmental protection;
- reduction of the total amount of waste directed to landfills;
- elimination of the malpractice of illegal waste storage;
- creating and launching a database of products, containers, and waste management (BDO).

According to the 2012 data from the Central Statistical Office (GUS), the proportion of recycled waste in the years 2010-2011 decreased by 9.2%, while the proportion of stored waste increased by 21.1% in relation to the years 2000-2005. This data shows the necessity for developing technologies of waste processing into usable products [Borowski 2013].

According to other researchers [Hejft 2002, Laskowski and Skonecki 2001; Skonecki and Laskowski 2012; Mediavilla et al. 2009, 2012; Mani et al. 2006; Shaw 2008; Shaw et al. 2009; Kaliyan and Morey 2009, Niedziółka et al. 2008; Szpryngiel et al. 2011; Niedziółka et al. 2015], who deal with the issue of renewable energy, one of the methods of utilization of various kinds of plant waste **is its processing in through pressure agglomeration into the form of a solid fuel (pellets, briquettes)**.

The overreaching aim of producers of solid fuels is seeking to obtain high quality products characterized by high values of the coefficient of kinetic durability and high density. In practice, this is difficult to achieve due to the impact of numerous factors [Laskowski 1989; Czaban 2000, Demianiuk 2001, Grochowicz 1996, Hejft 1991; 2002; Obidziński et al. 2006]: chemical and biological (chemical composition of the densified material, biological structure of its particles), material (e.g. moisture content of the material, granulometric composition of particles of the densified material), construction of the working system (e.g. matrix diameter; diameter and number of densification rolls; diameter, length, and condition of the surfaces of matrix openings; the size of the gap between the matrix and the roll), and process (e.g. densifying pressures, flow rate of the densified material, densification speed, process temperature, conditioning).

In the coming years, among the most prospective sources for the production of clean, ecological energy there will be post-production waste materials obtained during the processing of agricultural and food materials, e.g. buckwheat hulls obtained during the production of groats, rapeseed pellets obtained during the production of rape oil, potato pulp which is a byproduct of starch production, corn bran obtained during the production of flour and other corn products, fruit pomace obtained during the production of fruit juice, and many more.

In Poland, using post-production waste from the food and agricultural industry as potential raw materials for energy production is also legally sanctioned (e.g. by the 14 August 2008 Regulation of the Minister of Economy, which obligates to increasing the proportion of energy from renewable sources, the so-called "green energy", in Poland's fuel-energy balance).

4.3. AIM OF RESEARCH CONSTITUTING THE SCIENTIFIC ACHIEVEMENT

The aim of the conducted research presented in **publications no. 1-no. 6** (constituting the scientific achievement) was to:

- analyze the usability of plant waste materials as a raw material for pressure agglomeration,
- determine the usability of potato pulp (a waste material characterized by a high moisture content) as a binder material,
- determine the most beneficial (optimal) parameters of the process of pelletization of selected waste materials from the point of view of power consumption of the pelleting device and the quality of the obtained product (pellets).

4.4. RESEARCH RESULTS

1) publication no. 1:

One of the types of industrial waste of plant origin, classified as noxious waste, is tobacco waste, which is obtained at different stages of tobacco and cigarette production. This waste has different forms, usually consisting of residue of tobacco leaves, shavings, and dust of various grain sizes (from several μm to 1 mm).

Tobacco waste containing relatively large amounts of tobacco dust is also dangerous for people's health as inhaling them may lead to allergies and other immunotoxic disorders [Piotrowska-Cyplik et al. 2008]. It was established in initial tests that the dominant fractions in waste are those with a particle size of 0.5 mm, which comprise approx. 62 %, 1 mm (approx. 16 %), and 0.25 mm (approx. 16 %). Moreover, tobacco waste is characterized by a very low moisture content of approx. 9% and a low bulk density – approx. 300 kg/m^3.

In order to eliminate the inconveniences connected with storage, warehousing, and dangers posed by fine fractions of tobacco waste to people's health, it was decided that it would be subjected to the process of pressure agglomeration into the form of pellets. Tests connected with determining the usability of tobacco waste from British-American Tobacco in Augustów for pellets production are presented in **publication no. 1**:

Obidziński S. (2011). Tests of the densification process of tobacco waste. Inżynieria i Aparatura Chemiczna No. 1, 50(42), 29-30.

In this publication, determined were the most beneficial material and process parameters (moisture content of waste and process temperature) from the point of view of the values of densifying pressures and the density of pellets obtained from tobacco waste in the process of its pelleting.

The research was carried out on a test stand in a "open densification chamber – densifying piston" system, which was modernized for the needs of the conducted research. A heating band (put on the thermostatic element) coupled with a temperature controller was used to heat the chamber. Using the band allowed to achieve a process temperature of over 100 °C. Densification of material was carried out by means of a piston with a strain gauge that made it possible to record the acting forces on the piston.

The paper presents the results of tests of the influence of moisture content of waste (9%, 12%, and 15%) and process temperature (40 °C, 60 °C, 80 °C, and 100 °C) on the densifying pressures in the process of its pelletization and the density of the obtained pellets. The tests were carried out with the use of a matrix with an opening diameter of 8 mm and length of 47 mm. The mass of each of the densified samples was 0.5 g.

The research presented in the publication allowed to conclude that both the temperature of the pelleting process and the moisture content of the densified material have a significant influence on the values of maximum densifying pressures and the density of the obtained pellets.

According to the conducted tests, increasing the moisture content of the densified material from 9% to 12% results in an increase of maximum densifying pressures and an increase of pellets density.

A further increase of the moisture content from 12% to 15% results in a slight decrease of the densifying pressures and a reduction of pellets density. Pellets of the highest quality (the highest density – approx. 1320 kg/m^3) were obtained at a moisture content of 12% and a temperature of 100 °C.

Increasing the process temperature in the range of 40 to 100 °C results in an increase of the density of the obtained pellets. The range of temperatures for the process of densification of tobacco waste that allows to obtain pellets densities of over 1000 kg/m^3 is from 60 to 100 °C.

The increase of pellets density along with the increase of temperature is caused by changes occurring in the material during densification as a result of the action of temperature. As temperature is increasing, viscosity of the liquid contained in the densified waste is decreasing, which has a beneficial influence on movements of waste particles in relation to each other, and their "fitting" and packing as a result of the densifying piston's load. Only at the material's moisture content value of 15%, after exceeding a temperature of 60 °C, did a reduction of the density of the obtained pellets occur. This reduction was caused by the increase of the amount of steam from moisture (as a result of the action of temperature and the densifying pressure). After a pellet leaves the densification chamber, the steam emanating from it causes the weaker bindings created during densification to break and the pellet to "expand" (its volume increases), resulting in a reduction of pellets density. Apart from this, observed was also the phenomenon of the material adhering to the walls of the chamber and the densifying piston, which was another cause for the reduction of pellets density due to loss of matter from the pellet surface. The surface of the obtained pellets was rough.

From the point of view of energy consumption of the process, the preferred range of temperatures at which densification of tobacco waste should be carried out is from 70 to 100 °C. Within this range, a reduction of the values of maximum densifying pressures occurs, as well as a further increase of the density of the obtained pellets.

The performed tests showed that the most beneficial value of moisture content of the densified waste is 12 %. At this value, pellets of the highest quality were obtained (the highest density and a smooth, shiny pellet surface). Apart from this, at this value of the moisture content, the negative effect the densified material adhering to the walls of the densification chamber and the densifying piston (as was the case at the moisture content value of 15%), which led to a reduced density of the obtained pellets, did not occur.

The research showed that tobacco waste is a material characterized by a high susceptibility to densification, as evidenced by the low obtained values of maximum densifying pressures (from 1.25 to 24.33 MPa), which are lower than the corresponding values for densified fodder (approx. 26-36 MPa) [Obidziński 2005], i.e. materials considered as highly susceptible to densification.

The research presented in **publication no. 1** confirmed the usability of tobacco waste as a raw material (sourced from the so-called "non-forest biomass") for the production of heating pellets in the process of pressure agglomeration. The obtained high values of pellets density attest to their high resistance to storage conditions, while the low values of densifying pressures are more beneficial from the point of view of the costs of process implementation (low energy consumption of the pelleting process) in the working system of the pellet mill.

The most beneficial process and material parameters presented in the publication were used in tests of the process of pelletization of tobacco waste in the working system of a prototype pellet mill with a flat matrix.

At the same time, the findings are in accordance with the data presented by Poskrobko [Pokrobko et al. 2010] and Król [Król et al. 2010], who describe tobacco waste as a material characterized by good energy properties that can be successfully used as a raw material for the production of a solid fuel (in the form of pellets) for electric energy and heat production.

2) publication no. 2:

Tests of the process of pelleting of a mixture of tobacco waste with a fine-grained lemonbalm waste content were presented in **publication no. 2:**

Obidziński S. (2012). Pelletization process of postproduction plant waste. International Agrophisics. Vol. 26(3), 279-284. (JCR), IP=1.574, MNiSW=20.

The research presented in **publication no. 2** was the effect of the results obtained during densification of tobacco waste **(publication no. 1)** and the high quality pellets obtained at low values of densifying pressures, which prompted further research into producing pellets from a mixture of tobacco waste with a material characterized by a low susceptibility to densification, as shown in initial tests, i.e. fine-grained lemonbalm waste. The assessment of energy properties of lemonbalm together with the initial densification tests of the susceptibility of lemonbalm waste to densification were described in paper [Obidziński 2010].

When commencing the tests, an analysis of literature reports concerning utilization of herbal waste was performed. It showed that herbal waste (e.g. lemonbalm) is usually sold by companies for small sums or even given away for the price of transport [Obidziński 2010], which is a significant factor when the waste is used as a raw material or a component with other waste for the production of, for example, heating pellets.

On the basis of the properties of tobacco waste (presented in **publication no. 1**) and lemonbalm waste [Obidziński 2010] determined in the initial tests, it was decided that 10 %, 20 %, and 30 % additions of fine-grained lemonbalm waste would be introduced to the tobacco waste in the performed tests of the densification process. The introduction of lemonbalm waste (characterized by an approx. 42 % proportion of 0.125 mm particles and an approx. 35 % of 0.25 mm particles as well as a low susceptibility to densification) to tobacco waste (characterized by a high susceptibility to densification) was believed to minimize the inconvenience connected with the negative impact of fine fractions in lemonbalm waste on the densification process and the quality of pellets.

The moisture content of the waste (both tobacco and lemonbalm) used in the tests was 12 %. The tests were carried out on a work stand in the "open densification chamber – densifying piston" system (described in **publication no. 1**). The tests of pelleting of tobacco-lemonbalm waste mixtures were performed according to Hartley's PS/DS-P experiment plan, adopting the following independent variables: content of lemonbalm waste in the mixture (10%, 20%, and 30 %), process temperature (40 °C, 60 °C, and 80 °C), length of matrix openings (37 mm, 42 mm, and 47 mm), and mass of the densified sample (0.3 g, 0.6 g, and 0.9 g).

Increasing the process temperature (the temperature of the densified waste and that of the working chamber) from 40 to 80 °C, and increasing the length of the matrix openings from 37 to 47 mm, resulted in an increase of the maximum densification pressures obtained during the process of densification of the mixture of tobacco and lemonbalm waste. The increase of the values of pressures along with the increase of temperature is caused by adhesion of the densified material to the chamber walls during densification, which leads to an increase of resistances to forcing. It was particularly apparent in the range of temperatures of 60÷80 °C. The increase of the maximum densification pressures along with the increase of the matrix length, on the other hand, is the result of the increase of the real surface of friction between the particles of the densified mixture and the chamber walls.

As a result of the research described above, it was also observed that both an increase of the mass of the sample of the densified mixture from 0.3 g to 0.9 and an increase of the content of lemonbalm waste in the densified mixture from 10 to 30 % resulted in an increase of the density of the obtained pellets. The increase of the density of the obtained pellets along with the increased lemonbalm content is caused by an increase of the proportion of fine-grained particles (with the increasing content of lemonbalm in the densified mixture), which resulted in an increase of the degree of "packing" of particles in the densified mixture. The increased density of the produced pellets along with the increased mass of the densified sample are connected with increasing resistances to forcing of the densified mixture resulting from the increase of forces of friction between the densified mixture and the walls of matrix openings, which had an impact on the increase of the values of densifying pressures.

Increasing the process temperature from 40 to 80 °C as well as the length of matrix openings from 37 to 47 mm also caused an increase of the density of the obtained pellets. As a result of the high temperature and the reduction of viscosity of the liquid contained in the densified waste mixture, the more beneficial movement and "fitting" of fine particles between larger ones occurred, which resulted in their better "packing" under densifying piston's load. The increase of pellets density along with the increase of matrix length, on the other hand, was the result of the significant increase of the densifying pressures that resulted from the increase of resistances of friction between the densified mixture and the matrix surface.

The most beneficial parameters, from the point of view of the density of the obtained pellets of over 1100 kg/m^3, is a range of temperatures of tobacco and lemonbalm waste pelleting of 60-80°C, a matrix opening length of 47 mm, a lemonbalm waste content in the densified mixture of approx. 20 %, and a mass of the densified waste of 0.6 g.

The research presented in **publication no. 2** allowed to conclude that a mixture of post-production tobacco waste and lemonbalm is a material highly susceptible to densification, which can be used as a heating fuel owing to its high energy properties, as confirmed in earlier research studies [Król et al. 2010, Obidziński 2010].

3) publication no. 3:

Another post-production waste of plant origin from the food and agricultural industry, which may be a rich source of the so-called "non-forest biomass" is potato pulp, obtained as post-production waste during the production of potato starch. It is a relatively troublesome and difficult to utilize organic residue material after starch and most of the juice are washed out from the potatoes.

For instance, during their annual 90-day potato campaign, the Łomża-based PEPEES S.A plants process approx. 150,000 tons of potatoes, at a low crop yield of the material. This results in producing waste in the form of approx. 22,500 tons of pressed pulp with a moisture content of approx. 80 %, which in terms of dry substance gives approx. 4,500 ton of dry matter. This is a very interesting quantity even from the point of view of professional energetics [Niesteruk et al. 2008]. As there is only a small interest on the part of farmers in using pulp as a fertilizer (in compost form) or as fodder filling, as well as the small interest in its use as substrate for the production of biogas, the plants that generate this waste are searching for a method of disposal of the troublesome and expensive burden. On the basis of initial tests, it was decided that usability of potato pulp sourced from the PEPEES S.A plants in Łomża as a future ecological solid fuel would be determined, which was presented in **publication no. 3:**

Obidzinski S. (2012). Analysis of usability of potato pulp as solid fuel. Fuel Processing Technology 94(2012), 67-74. (JCR), IP=2.945, MNiSW=32.

As part of the analysis in **publication no. 3**, performed were: determination of the contents of elemental composition (chlorine, sodium, potassium, phosphorus, and nitrogen), assessment of the energy properties of pulp (absolute moisture content of pulp, heat of combustion and calorific value, ash content in pulp), assessment of the energy consumption of the densification process of pulp, and assessment of the quality (density) of pellets from pulp.

The determination of the elemental composition of pulp, i.e. determination of ash content and the contents of chlorides, sodium, potassium, phosphorus, and total nitrogen, was performed due to their significant impact on combustion processes.

The results of determinations of the contents of chlorides, sodium, potassium, phosphorus, and total nitrogen in potato pulp (table 1) indicate that none of the contents of elements determined for pulp exceeds the threshold values for the bubbling fluidized-bed boiler (table 1).

Table 1. Results of determinations of dry matter, sodium, potassium, phosphorus, and chlorides in samples of pellets from pulp [Niesteruk et al. 2008]

No.	dry matter [%]	Na [mg/kg]	K [mg/kg]	P [%]	Cl^- [mg/kg]	total nitrogen [%]
Pulp	70.6 ± 3.5	102 ± 10	2190 ± 22	0.034 ±0.003	124 ± 12.4	0.474 ± 0.02
Threshold values for the bubbling fluidized-bed boiler	-	0.05% (500mg/kg)	0.3% (3000mg/kg)	0.07 % (700mg/kg)	0.06% (600mg/kg)	0.68 % (6800mg/kg)

The performed determinations of the contents of elemental composition (chlorine, sodium, potassium, phosphorus, and nitrogen), i.e. the elements significant from the point of view of the process of combustion, allowed to conclude that fuel from potato pulp, in comparison with other types of biomass, may become an excellent and attractive boiler fuel, to be used in professional energetics. The use as an additive to other types of biomass, exceeding the threshold values for the determined elements, will also enable its industrial combustion.

The obtained values of the heat of combustion and calorific value of pulp show it to be a material of high energy properties. Its heat of combustion in the dry state is 16.33 MJ/kg, while the calorific value is 15.41 MJ/kg. Pulp's moisture content has a significant impact on the values of its heat of combustion and calorific value. In **publication no. 3**, a mathematical model was created that shows the relationship between the heat of combustion and the moisture content of pulp. The obtained research results, in comparison with other plant materials, show that pulp is a material of energy properties similar to other plant waste, such as straw, rapeseed oil cake, sawdust, or paper, among others [Obidziński 2004; Komorowicz et al. 2009; Stolarski et al. 2007; Cieślikowski et al. 2006].

Tests of the densification process of potato pulp were carried out on a work stand in the "open densification chamber – densifying piston" system, described in **publication no. 1.** The tests were performed according to Hartley's PS/DS-P4 experiment plan. The input values were the material and process parameters: pulp moisture content (35%, 40%, and 45%), pulp and working system temperature (40 °C, 60 °C, and 80 °C), average diameter of a pulp particle (0.5 mm; 1.5 mm, and 2.5 mm), and size of a densified sample (1 g; 1.5 g, and 2 g).

On the basis of the performed tests, it was concluded that increasing both the process temperature (pulp temperature and working chamber temperature) and the moisture content of pulp causes a reduction of densifying pressures. Increasing the mass of a pulp sample from 1 to 2 g caused an increase of densifying pressures. The increase of pressures is caused by the increase of the mass of pulp, resulting in an increased real friction surface, which causes an increase of resistances to friction between the densified pulp and the chamber walls.

The reduction of maximum densifying pressures as pulp particle size increases from 0.5 to 2.5 mm is the result of the reduced real surface of contact of 2.5 mm particles, in comparison with 0.5 mm particles, with the surface of the wall of a matrix opening.

Increasing the process temperature (pulp temperature and working chamber temperature) from 40 to 80 °C causes an increase of pellets density. The observed increase of density is caused by the higher degree of gelatinization of starch in the pulp as a result of the action of temperature and the creation of stronger inter-particle bindings in the obtained pellets.

Increasing the moisture content of pulp, on the other hand, within the range of 35 to 45 % causes a reduction of the density of the obtained pellets. The steam from moisture contained in pulp produced in a high temperature lowers the strength of bindings in the produced pellets, which has a negative impact on pellets density.

Increasing the mass of the densified sample from 1 to 2 g causes an increase of pellets density. The observed increase is connected with the increasing resistances to forcing of the densified mixture resulting from the increase in the real surface of friction between the densified mass and the walls of matrix openings.

Reducing the size of pelleted pulp within the range of 2.5 to 0.5 mm results in an increase of pellets density. This is caused by the increased reduction of free inter-particle space during densification, which has a positive impact on the increase of pellets density.

The research presented in **publication no. 3** allowed to conclude that potato pulp is a material of high energy properties (high heat of combustion and calorific value), with low contents of ash remaining after the process of combustion. Determinations of the composition of elements significant in the combustion process (chlorine, sodium, potassium, phosphorus, and nitrogen) allow to conclude that fuel from potato pulp, in comparison with other types of biomass, is a good and attractive boiler fuel. Tests of potato pulp densification showed that densification is possible after its moisture content is reduced to approx. 35-45%. The conducted tests showed that pulp dried down to a moisture content of 35-45 % is characterized by a high susceptibility to pelleting and can be used as a material for producing ecological solid fuel in the form of pellets or heating briquettes.

4) publication no. 4:

A continuation of the research presented **in publication no. 3** were the tests of the pelleting process of granary waste in the form of oat bran and potato pulp, presented in **publication no. 4:**

Obidzinski S. (2013). Assessment of the process of production of heating pellets from oat bran with a potato pulp content. Acta Agrophysica, Vol. 20(2), 389-402. ISSN 1234-4125. MNiSW=7.

The tests presented in **publication no. 4** were the result of conclusions drown from the research presented in **publication no. 3** and literature reports [Miranda et al. 2012; Stahl and Berghel 2011; [Filbakk et al. 2011; Poskrobko et al. 2010, Gil et al. 2010, Gil et al. 2010a; Wandrasz and Wandrasz 2006; Moran et al. 2009], according to which it is possible to convert post-production plant waste, in connection with other plant waste, into the form of pellets.

The aim of the paper was to determine the influence of the content of non-dried potato pulp (with a moisture content of approx. 88%) in a mixture with oat bran on the energy consumption of the process of pelleting and the quality of the obtained pellets, in the aspect of their use as a fodder or a heating fuel.

The tests of the densification process of the mixture of potato pulp and oat bran were carried out on a test stand in the "open densification chamber – densifying piston" system, described in **publication no. 1**. During the tests, a mixture composition (potato pulp-oat bran) optimal for the pelleting technology was sought, to ensure an adequate quality of the obtained pellets. The process of densification was performed for the prepared mixtures with mass ratios of potato pulp in a mixture with oat bran of 10%, 20%, and 30%. The tests were carried out in an open chamber with a diameter of 8 mm and length of 47 mm, in temperatures of 50 °C, 70 °C, and 90 °C, by densifying (forcing) 20 samples with a mass of 1g for each of the measurement points.

According to the obtained test results, increasing the content of potato pulp in a mixture with oat bran from 10 to 20% caused an increase of densifying pressures by approx. 123 %, at a temperature of 50°C (from 3.72 to 8.30 MPa); and by as much as approx. 248% at a temperature of 90°C (from 2.66 to 9.26 MPa). The increase of densifying pressures along with the increase of pulp contents was caused by the increase of the moisture content of the mixture (from 13.38% to 20.40 %), causing an increase of the amount of binder in the mixture, which in contact with the surface of a matrix opening caused an increase of resistances to forcing (the mixture no longer slid on the surface of matrix openings, as was the case for a 10% pulp addition to oat bran) and, in consequence, higher densifying pressures.

A further increase of the content of potato pulp in the mixture from 20 to 30 % caused a reduction of densifying pressures by approx. 58% at a temperature of 50°C (from 8.30 to 3.48 MPa) and by approx. 62.5% at a temperature of 90°C (from 9.26 do 3.44 MPa). This was the result of an increase of the moisture content of the mixture from 20.40% to 29.58%. The same moisture content value caused large amounts of liquid to appear in the mixture, which acted as a "lubricator" at contact between the densified mixture and the matrix opening during densification and, in consequence, resulted in a reduction of densifying pressures.

The performed one-way analysis of variance (one-dimensional Kolomogorov-Smirnov significance test) at a significance level of P = 0.05 allowed to observe significant differences between the values of maximum densifying pressures obtained at an increasing content of pulp at each of the tested temperatures. No significant differences between the values of maximum densifying pressures at a temperature of 50°C at pulp contents of 10 and 30%, and those obtained at a temperature of 70°C at pulp contents of 20 and 30% were observed.

Increasing the temperature of the pelleting process of oat bran, at a potato pulp content of 10%, from 50 to 90°C caused a reduction of densifying pressures by approx. 40% (from 3.72 to 2.66 MPa). Another tendency was visible at pulp contents in the mixture with oat bran of 20 and 30%. In this case, increasing the temperature of the pelleting process from 50 to 70°C caused an increase of pressures by approx. 12.5% at a pulp content of 20% (from 8.30 to 9.33 MPa), and an increase of pressures by approx. 50% at a pulp content of 30% (from 3.48 to 5.22 MPa). A further increase of temperature from 70 to 90°C caused a reduction of densifying pressures. The reduction of densifying pressures after a temperature of 70°C had been exceeded was caused by the increase of the degree of gelatinization of starch contained in the pulp and the creation of increasingly large amounts of binder (a mixture of starch and moisture) at increasing temperatures, which contributed to the decrease of resistances to forcing and a reduction of the values of densifying pressures.

The performed one-way analysis of variance (one-dimensional Kolomogorov-Smirnov significance test) at a significance level of P = 0.05 allowed to observe significant differences between the values of pellets density obtained at an increasing pulp content for each of the tested temperature values.

The conducted tests showed that at a pulp content lower than 20%, the quality of pellets was low. The pellets fell apart and crumbled easily. In this case (at lower pulp contents) oat bran should be shredded, which would lower its tendency to slide on the matrix openings and facilitate its binding inside a pellet with the gelatinizing action, under the influence of temperature and moisture, of starch from pulp.

Increasing the pulp content in the mixture with oat bran from 10 to 20% had an impact on the increase of the density of the obtained pellets by approx. 15.5% at a temperature of 50°C (from 719.11 to 840.94 kg/m^3), and by approx. 14% at a temperature of 90°C (from 790.94 to 920.95 kg/m^3). An increase of the density of the obtained pellets along with the increase of pulp content was caused by the increase of the amounts of binder (created from starch and moisture) that appeared in the mixture along with the increase of the amount of pulp. An increase of the amounts of binder resulted in creating increasingly stronger bindings between mixture particles and, in consequence, resulted in an increased pellets density.

A further increase of pulp content in the mixture with oat bran from 20 to 30% had an impact on the reduction of the density of the obtained pellets by approx. 25% at a temperature of 50°C (from 840.94 to 671.24 kg/m^3) and by approx. 43% at a temperature of 90°C (from 920.95 to 530.10 kg/m^3). Increasing the pulp content in a mixture with oat bran from 20 to 30% caused an excessively high increase of moisture content of the mixture from 20.40% to 29.58%, which caused an expansion of the newly-produced pellets as a result of evaporation of excess water contained in the mixture, after leaving the densification chamber.

Increasing the temperature of the pelleting process of the mixture from 50 to 90°C caused an increase of the density of the obtained pellets by approx. 10% (from 719.11 to 790.94 kg/m^3) at a pulp content of 10%, and by approx. 9.5% (from 840.94 to 920.95 kg/m^3) at a pulp content in the mixture of 20%. This increase was caused by the increase of the degree of gelatinization of starch contained in the pulp and the creation of increasingly large amounts of binder (a mixture of starch and moisture), which led to creating increasingly stronger bindings between mixture particles and, in consequence, resulted in an increase of pellets density.

Only at a pulp content of 30% in the mixture with z oat bran, did increasing the process temperature from 50 to 90°C cause a reduction of the density of the obtained pellets by approx. 11% (from 671.24 to 530.10 kg·m^{-3}). In this case, increasing the temperature of the pelleting process caused an expansion of the newly-produced pellets as a result of evaporation of excess water contained in the mixture at an increasing process temperature. Expansion of the newly-produced pellets resulted in a reduction of the density of the obtained pellets.

The obtained values of pellets density (approx. 921 kg/m^3) at a pulp content of 20% and a temperature of over 90°C allowed to conclude that the obtained pellets are of a high quality and constitute a solid fuel of full quality.

In **publication no. 4**, the influence of pulp content in a mixture with oat bran and process temperature on the maximum densifying pressures obtained in the process of pelleting and the density of the obtained pellets was described by equations.

An analysis of non-linear regression of the obtained equations at a significance level of P=0.05 was also performed, which allowed to observe the significance of individual terms in the assumed models. The performed analysis allowed to conclude that the significant terms in the assumed models are only the terms connected with moisture content.

The test results presented in **publication no. 4** enabled a preliminary determination of parameters of implementation of the process of densification in the working system of a pellet mill with a flat matrix.

5) publication no. 5:

After determining the parameters of implementation of the process of pelletization of a mixture of oat bran and potato pulp performed on a work stand in the "open densification chamber –

densifying piston", described in **publication no. 4**, it was decided that tests of the pelleting process in a working system of a pellet mill with a flat rotating matrix working with densification rolls would be performed. These tests were described in **publication no. 5:**

Obidzinski S. (2014). Pelletisation of biomass waste with potato pulp content. International Agrophisics. Vol. 28(1), 85-91. (JCR), IP=1.025, MNiSW=25.

In the course of the tests (presented in **publication no. 5**), the influence of potato pulp content in a mixture with oat bran on the power demand of the motor driving the pellet mill and the kinetic durability of the obtained pellets were determined. Based on the experience gained in research presented in **publication no. 4**, a decision was made to change the amounts of pulp introduced into the mixture with oat bran to 15 %, 20 %, and 25 %.

The tests of the densification process of the mixture of potato pulp and oat bran were carried out on a stand whose main component is a P-300 pellet mill with a flat matrix. The working gap between the densification roll and the matrix was 0.4 mm, the mass flow rate of the mixture was 150 kg/h, while the rotational speed of the matrix was 280 rpm. The matrix used for the tests had openings with a diameter of 8 mm and length of 28 mm.

The kinetic durability of the obtained pellets was determined pursuant to PN-R-64834:1998, 24 hours after the pellets had left the working system, using Holmen's and Pfost's testing machines.

The obtained test results, presented in **publication no. 5**, allowed to conclude that increasing the potato pulp content from 15 to 25 % in a mixture with oat bran caused a significant reduction of the power demand of the pellet mill, by approx. 41 % (from 3.69 to 2.18 kW).

The reduction of the power demand of the pellet mill is a result of the significant increase of moisture content caused by the increase of potato pulp content, which was also confirmed by tests presented in **publication no. 4**. The average moisture content of the mixture increased from 18.50 % (at a 15% pulp content in the densified mixture) to 31.33 % (at a 25% pulp content in the densified mixture). Increasing the pulp content caused the appearance of increasingly high amounts of binder (in the form of a viscuous liquid created from starch and moisture) during the pelleting process. The created excessive amounts of binder (at a pulp content of 25%) caused a reduction of resistances to forcing, along with a reduction of the values of the power demand of the pellet mill, at the same time retaining a satisfactory kinetic durability of the obtained pellets, which in combination with the bran, after cooling and gelatinization of starch into a sticky gel, produced a dense agglomerate.

The influence of pulp content z_w on the power demand of the pellet mill N_g during the densification of oat bran and potato pulp in the working system of a pellet mill with a flat matrix is described by a general equation of the exponential function:

$$N_g = 8.26e^{-0.053z_w} \quad (1)$$

where: z_w – potato pulp content in the mixture [%].

At a test time of 30 s, the kinetic durability decreased by approx. 22%, from 98.42% to 76.64%. At a test time of 60 s (the appropriate test time for pellets of 8 mm in diameter, pursuant to PN-R-64834:1998), the kinetic durability of the pellets decreased by approx. 31%, from 95.78% to 65.90%. Increasing the test time to 90 s resulted in reducing the kinetic durability by approx. 45%, from 95.24% to 52.66%.

Similar results as to the values of kinetic durability of pellets to those obtained for a Holmen's test time of 60 s were obtained in Pfost's test. Increasing the pulp content in a mixture with oat bran from 15 to 25% caused a reduction of the kinetic durability of pellets by approx. 30%, from 96.22% to 67.10%. The value of the kinetic durability of pellets determined with the use of Pfost's method is higher by approx. 1% than the value determined with the use of Holmen's method, which allowed to conclude that both these methods can be used interchangeably in future research. Holmen's method is, however, far less time-consuming.

The relationship between kinetic durability of the pellets P_{dx} and potato pulp content z_w in a mixture with oat bran, at each of Holmen's test times, as well as for Pfost's test, was described by a second degree polynomial:

$$P_{dx} = Az_w^2 + Bz_w + C \qquad (2)$$

where:
z_w – potato pulp content in the mixture [%].
A, B, C – coefficients.

The tests carried out in the working system of the pellet mill allowed to conclude that the most beneficial content of pulp as an additive to oat bran, from the point of view of the power demand of the pellet mill, is 20%, as it allows to significantly reduce the energy consumption of the process (at a pulp content of 15%, the power demand falls by approx. 19%, from 3.69 to 2.98 kW, making it possible at the same time to obtain pellets of a satisfactory quality (kinetic durability of over 90%). Increasing the pulp content to 25% resulted in an additional reduction of the power demand by approx. 22 %, but this also caused a reduction of kinetic durability to a value below 70%, which renders the obtained pellets' quality unsatisfactory.

The tests performed in the working system of the pellet mill allow to conclude that the most beneficial content of pulp as an additive to oat bran, from the point of view of the quality of pellets, was 15 %, as it allowed to obtain high quality pellets (pellets of a kinetic durability of over 95 %). Increasing the pulp content above 20% (at its operational moisture content of approx. 85-88%) resulted in a reduction of the kinetic durability below 90%.

The research results presented in **publication no. 5** prove that an additive in the form of potato pulp to waste plant material of a low moisture content (in the case of **publication no. 5** – oat bran) is an excellent binder material allowing to increase the mixture's susceptibility to densification, which makes it possible to reduce the energy consumption of the pelleting process, making it possible at the same time to obtain pellets of satisfactory durability properties.

The research results obtained in **publication no. 5**, together with the results presented in **publication no. 4**, allowed to create detailed guidelines for a technology of production of heating (fodder) pellets with a potato pulp content, which resulted in the author's patent application [Obidziński 2012]:

Obidziński S.: Heating pellets and the technology of their production. Patent application P.398399 dated 12.03.2012. The Patent Office of the Republic of Poland. Warsaw 2012.

6) publication no. 6:

The high heat of combustion and calorific value of pulp (presented in **publication no. 3**), the anti-corrosion properties of pellets from biomass materials with a pulp content [Król 2012], and the experience gained during the research presented in **publication no. 5** (potato pulp as an additive to waste plant materials of a low moisture content is an excellent binder, allowing to increase the susceptibility to densification of other materials, whose susceptibility is lower, and to reduce the energy consumption of the pelleting process, making it at the same time possible to obtain pellets characterized by good durability properties), led to using pulp as a binder material with buckwheat hulls – another agricultural and food waste material with a low susceptibility to densification. The results of tests of the process of densification of a mixture of buckwheat hulls and potato pulp were presented in **publication no. 6:**

Obidzinski S. (2014). Utilization of post-production waste of potato pulp and buckwheat hulls in the form of pellets. Polish Journal of Environmental Studies. 2014, Vol. 23, No. 4, (art. w trakcie druku). (JCR), IP=0.462. MNiSW=15.

The aim of the research presented in **publication no. 6** was to determine the influence of a potato pulp addition to buckwheat hulls in the following proportions: 15%, 20%, and 25%, as well as the conditions of the pelleting process, i.e a variable rate of mass flow of the mixture through the working system of the pellet mill (50 kg/h, 75 kg/h, and 100 kg/h), on the energy consumption of the pelleting process and on the quality of the obtained pellets (density, kinetic durability, their heat of combustion and calorific value). The influence of the pelleting process on changes in water activity of the densified mixture and the obtained pellets in the aspect of their potential use as a fodder or a heating fuel was also determined in the paper.

The obtained test results allowed to conclude that increasing the potato pulp content from 15 to 25% in a mixture with buckwheat hulls caused a significant reduction of the power demand of the pellet mill. At a rate of mass flow of the mixture through the working system of the pellet mill of 50 kg/h, this reduction was approx. 35% (from 2.08 to 1.35 kW), by approx. 35% at a mass flow rate of the mixture of 75 kg/h (from 2.73 to 1.78 kW), and by approx. 51 % at a mass flow rate of the mixture of 100 kg/h (from 4.26 to 2.07 kW). The obtained reduction of the power demand of the pellet mill was mainly caused by the high increase of the moisture content of the mixture resulting from the increase in the potato pulp content from 15 to 25%. Buckwheat hulls are characterized by a low moisture content of approx. 9.2%. The average moisture content of the buckwheat hulls mixture increased from 18.63 % (at a pulp content in the densified mixture of 15%) to 26.23 % (at a pulp content in the densified mixture of 25%).

Increasing the rate of mass flow of the mixture through the working system of the pellet mill from 50 to 100 kg/h caused an increase of the power demand of the pellet mill. At a pulp content in the mixture of 15 %, this increase was approx. 105% (from 2.08 to 4.26 kW); at a pulp content in the mixture of 20%, the increase of the power demand of the pellet mill was approx. 49% (from 1.58 to 2.36 kW); while at a 25% pulp content in the mixture the increase of the power demand of the pellet mill was approx. 53% (from 1.35 to 2.07 kW). The observed increase of the power demand of the pellet mill results from the fact that at a larger amount of mixture fed to the working system of the pellet mill, the amount of material densified during a single cycle increases (the thickness of the layer of material fed into the matrix openings increases). The increased layer thickness in a single densification cycle results in increased resistances to forcing and, in consequence, an increase in the power demand of the pellet mill.

On the basis of the conducted tests, it was concluded that increasing the potato pulp content from 15 to 25% in the mixture with buckwheat hulls caused a reduction of the density and kinetic durability of pellets determined with the use of Holmen's method. The reduction of the density of the obtained pellets along with the increase of the potato pulp content from 15 to 25 %, at a rate of mass flow of the mixture through the working system of the pellet mill of 50 kg/h, was approx. 19.5% (from 1185.95 to 954.88 kg/m^3); by approx. 20.5% at a mass flow rate of the mixture of 75 kg/h (from 1134.42 to 902.49 kg/m^3); and by approx. 19 % at a mass flow rate of the mixture of 100 kg/h (from 1005.85 to 813.73 kg/m^3).

In the case of the kinetic durability of pellets, increasing the potato pulp content from 15 to 25 % in the mixture with buckwheat hulls, caused its reduction by approx. 6% at a rate of mass flow of the mixture through the working system of the pellet mill of 50 kg/h (from 98.85 to 93.22 %); by approx. 6% at a mass flow rate of the mixture of 75 kg/h (from 96.09 to 90.74 %); and by approx. 11 % at a mass flow rate of the mixture of 100 kg/h (from 93.58 to 83.22%).

Increasing the rate of mass flow of the mixture through the working system of the pellet mill from 50 to 100 kg/h caused a reduction of both the density and the kinetic durability of pellets. The highest reduction of the density and the kinetic durability of pellets, along with the increase of the rate of mass flow of the mixture through the working system of the pellet mill from 50 to 100 kg/h, was observed at a pulp content in the mixture of 25 % – a reduction of pellets density by approx. 15 % (from 954.88 to 8132.73 kg/m^3) and a reduction of the kinetic durability of pellets by approx. 11% (from 93.22 to 83.22 %).

The obtained results for the density and the kinetic durability of pellets from a mixture of buckwheat hulls and potato pulp allowed to conclude that at a content of 15 %, pellets of a high quality, i.e. a density of over 1000 kg/m^3 and a kinetic durability of over 93% (at each of the tested rates of mass flow of the mixture through the working system of the device) are produced. The obtained pellets from buckwheat hulls at a pulp content of 15% fully meet the requirements of the norms pertaining to wood pellets in European countries [Wach 2005, Hiegl et al. 2009] as well as the following requirements: EN 14961 and PN-EN 14961 [EN 14961; ALAKANGAS 2012]. According to these norms, a solid fuel of a full quality is one whose density exceeds 1000 kg/m^3 [Obidziński 2013]. Pellets from buckwheat hulls with a pulp content of 20 % fully meet the requirements of EN 14961-6 [EN 14961-6], which determines the quality classes for fuel and the specifications for non-forest pellets for non-industrial use.

Increasing the potato pulp content from 15 do 25 % in the mixture with buckwheat hulls caused a significant reduction of the water activity of pellets and their moisture content, determined immediately after the densification process, in comparison with their values prior to the densification process. Increasing the potato pulp content from 15 do 25 %, at a rate of mass flow of the mixture through the working system of the pellet mill of 50 kg/h, caused a reduction of the water activity of the obtained pellets by approx. 6 % (from 0.916 to 0.971); at a rate of mass flow of the mixture through the working system of the pellet mill of 75 kg/h – also by approx. 6 % (from 0.905 to 0.962); and at a rate of mass flow of the mixture through the working system of the pellet mill of 100 kg/h – a reduction by approx. 10.5 % (from 0.860 to 0.950). The obtained values of water activity and moisture content of pellets after the process are much too high to prevent mould growth in the tested pellets. Research by Szlachta and Podawiec (2007) show that moulds grow in fodders whose a_w is at a level of 0.60 to 0.75. Due to this, the obtained pellets need to be subjected, after pelleting, to cooling or drying, in order to reduce their water activity below 0.6.

Publication no. 6 presents the determined equation describing the influence of pulp content in a mixture with buckwheat hulls z_w on the heat of combustion of the mixture Q_s obtained during the combustion of buckwheat hulls and potato pulp:

$$Q_s = -0.013z_w + 19.434 \tag{4}$$

and an equation describing the influence of pulp content z_w on the calorific value of the waste mixture Q_i:

$$Q_i = -0.029z_w + 18.725 \tag{5}$$

On the basis of the obtained equations, it was concluded that increasing the pulp content from 0 to 25% caused a slight reduction of the heat of combustion, from 19.44 to 19.09 MJ/kg (for the dry mass of the mixture). The obtained heat of combustion and calorific values prove that the tested mixtures of buckwheat hulls and potato pulp are a material characterized by high energy properties. The values of the heat of combustion of buckwheat hulls obtained in the tests are similar to those obtained by Stolarski and Kwiatkowski [2009], according to whom the heat of combustion of pellets from buckwheat hulls was 19.99 MJ/kg, the hulls characterized by a similar value.

4.5. DISCUSSION OF RESULTS

The performed tests of the densification process, presented **in publications no. 1-no. 6**, allowed to ascertain the usability of post-production waste materials from the food and agricultural industry for pellets production. Adequately chosen parameters connected with: preparation of waste, implementation of the process of densification, and the design of the densifying working system, make it possible to obtain pellets of a high quality (a density of over 1000 kg/m^3 and a kinetic durability of over 95%), at moderate energy consumption.

Papers describing research studies connected with the use of post-production tobacco waste as a raw material for the production of heating pellets have not been found in the available literature. According to numerous authors, e.g. [Piecuch et al. 1997; Piotrowska-Cyplik et al. 2006; Çerçiolu, et al. 2008], tobacco waste, e.g. in the form of dust, is processed into the form of briquettes and subjected to the process of composting. In these papers, the authors do not describe the influence of material parameters on the course of the densification process, or on the quality of the obtained briquettes, which are assessed only from the point of view of their usability for composting.

It is possible to briquet other tobacco waste – post-harvest waste in the form of stalks. According to Peševski [Peševski et al. 2010], owing to the high calorific value of over 18,000 kJ/kg and the low nicotine content, tobacco stalks, processed into the form of briquettes, may constitute a heating fuel. In his paper, Peševski [Peševski et al. 2010] also does not describe the influence of material parameters on the course of the densification process. He only focuses on determining the qualitative characteristics of the obtained briquettes, i.e. heat of combustion, ash content, moisture content of briquettes, and their bulk density.

The undertaken tests of the process of densification of tobacco waste and their positive results are consistent with the ecological policy of Poland and the 2014 National Waste Management Plan [Monitor Polski No. 2010], as they show the possibility of increasing the proportion of recycling of waste, through its use as a potential raw material for pellets production, with a possibility of their use as a fodder or an energy source. This makes it possible to reduce the amount of waste directed to landfills and the malpractice of its illegal storage. The conducted tests (presented in **publication no. 1**) allowed to eliminate inconveniences connected with storage, warehousing, and danger to people's health (caused by fine-grained fractions) of tobacco waste. The technology of pressure agglomeration into the form of pellets proposed in relation to their utilization solves the problems of rational utilization of post-production tobacco waste.

Each of the cigarette factories operating in Poland (e.g. British-American Tobacco in Augustów) produces ten-twenty or more tons of waste in the form of dust or stalks daily, which until recently have been regarded as completely useless and dumped in large quantities onto spoil tips around tobacco plants. A few attempts at utilizing tobacco waste have been made so far [Piotrowska-Cyplik et al. 2006; Brohi et al. 1998; Çerçiolu et al. 2008; Öztürk, Bayraklı 2005], but this continues to be a real problem. According to Piotrowska-Cyplik and her colleagues [Piotrowska-Cyplik et al. 2008], the cheapest method of utilization of tobacco waste is using it as a fertilizer. Another method of utilization of tobacco waste is using it as a component for the production of lightweight structural concretes [Öztürk, Bayrakli 2005]. Some plants subject dusty tobacco waste to pressing into the form of briquettes, its further utilization, however, according to Piotrowska-Cyplik and her colleagues, is a serious environmental problem. The technology of its pressure agglomeration into the form of heating pellets, proposed in **publication no. 1**, and then using the pellets as a valuable source of thermal energy produced during the process of combustion, shows a real alternative possibility of its utilization. The properties of pellets from tobacco waste, despite the risk of corrosion of the combustion devices, as reported by Król and his colleagues [Król et al. 2010], at a level similar to bark or straw combustion (much lower than for bituminous coal combustion), predispose it for use as a potential source of energy produced in thermal processes.

One of the types of post-production waste produced in herbal plants is fine-grained waste produced during the packing of herbs (e.g. lemonbalm waste). In the case of the plants of Herbapol Białystok S.A., several tens of tons of waste are produced yearly. This waste is usually sold cheaply, e.g. for the price of transport. One of the methods of utilization of herbal waste is its use as a fodder additive [Hanczakowska 2007; Obidziński 2010]; however, a widespread use of this waste as a fodder additive requires much detailed research (e.g. nutritional) and obtain the necessary permits. They are also used to a small extent in the confectionery industry and as garden substrates [Hańczakowska 2007].

The main problem connected with its utilization is the low bulk density, below 300 kg/m^3, and the extremely small particle size. In the tested waste, the dominant fractions are those with diameters of 0.125 mm (42.28 % of the mass content) and 0.25 mm (34.65 %). The high proportion of fine-grained fractions has an impact on the significant increase of the energy consumption of the densification process, and also causes problems connected with the dusty fraction covering (gluing) the elements of the working system (densification rolls, matrix, piston) during the densification process. These problems result in such materials usually being subjected to non-pressure agglomeration, which, however, does not make it possible to obtain a product of satisfactory durability properties, one that would be resistant to storage and transport conditions, and does not ensure a suitably long shelf life (in the case of fodder materials).

The research presented in **publication no. 2** indicates a possibility of utilization of fine-grained herbal waste as a component (additive) when producing pellets from plant materials. The obtained results of the process of pelleting of a mixture of post-production tobacco waste and lemonbalm allow to conclude that the tested mixture, at adequately chosen material parameters, is a material that makes it possible to obtain high-quality pellets, similarly to the case of tobacco waste alone. These pellets can be used as a heating fuel, owing to their high energy properties, as confirmed in earlier research studies [Król et al. 2010, Obidziński 2010].

Papers describing research studies connected with the process of pelleting of fine-grained herbal waste have not been found in the available literature. There are, however, numerous research papers whose authors carried out the process of pelleting of green biomass: e.g. timothy hay [Tabeli et al. 2011], sorrel [Brozek and Novákováv 2004; Novakova and Brożek 2008], meadow hay [Nona et al. 2014; Niedziółka and Szpryngiel 2012], or grasses [Mani et al. 2006; Kronbergs and Smits 2008;

Gilbert et al. 2009; Kaliyan and Morey 2010; Rijal et al. 2012; Kaliyan et al. 2013; Maj and Piekarski 2013].

According to Gilbert [Gilbert et al. 2009], during pelleting of grass plants, the lignin they contain is softened in increased temperatures and acts as a binding material. Tests carried out by Gilbert [Gilbert et al. 2009] showed that the most beneficial temperature at which the softening occurs is approx. 70 °C.

Due to the marginal (a few per cent) proportion of dusty (fine-grained) fractions in the pelleted green materials, in comparison with fine-grained herbal waste, results of tests of the process of densification of these materials do not apply to densification of herbal waste.

Another type of post-production waste produced in plants from the food and agricultural industry that may constitute a rich source of the so-called "non-forest biomass" is potato pulp. It is a troublesome and difficult to utilize organic residue material after starch and most of the juice are washed out from the potatoes. For instance, during their annual 90-day potato campaign, the Łomża-based PEPEES S.A plants, at a low crop yield of the material, process approx. 150,000 tons of potatoes. This results in producing waste in the form of approx. 22,500 tons of pressed pulp with a moisture content of approx. 80 %, which in terms of dry substance gives approx. 4,500 ton of dry matter. This is a very interesting quantity even from the point of view of professional energetics [Niesteruk et al. 2008]. The positive results of the performed tests, presented in **publication no. 3**, indicate great possibilities of its utilization.

Currently, due to the small interest on the part of farmers in pulp use as a fertilizer (in compost form) or as fodder filling [Bogucki and Nej 2008], the plants that generate this waste are searching for a true and tried method of disposal of a troublesome and expensive burden. Despite the attempts at using pulp for ethanol production [Nowacki 2006; Białas et al. 2010; Kawa-Rygielska, Pęksa 2010], or methanol through anaerobic digestion [Czyżyk et al. 2010], these methods are not in common use.

The large amounts of the produced potato pulp, a plant fiber, seem to constitute an alternative fuel, even from the point of view of professional energetics. Its high energy properties were confirmed in **publication no. 3** and in other publications, e.g. in [Poskrobko et al. 2010]. This creates the possibility of its use for the production of solid fuels in the form of pellets or briquettes, which, after tests of the process of densification, was also supported by the author's patent application [Obidziński 2012].

Potato pulp is, however, a material characterized by a very high moisture content, exceeding 88 %, which poses a significant problem as far as using pulp as a solid fuel is concerned. The high moisture content of pulp as a raw material for the production of solid fuels can be reduced mechanically by means of the process of centrifugation, e.g. in a decanter centrifuge, down to a moisture content of approx. 45-40 %, then pelleting and drying the obtained pellets down to a moisture content of approx. 15 %. This method of solid fuel production from pulp will be far more beneficial economically than drying the pulp from a moisture content of approx. 88 % down to approx. 20 % and only then pelleting the dried pulp. Another method of reducing the high moisture content of potato pulp as a fuel is using it as an additive to other biomass waste characterized by a low moisture content (e.g. wood dust, straw, cereal bran, buckwheat hulls) subjected to pelleting.

Research of the pelleting process and pellets production also concentrates on searching for additives (the so-called binding agents) that improve the densified materials' susceptibility to pelleting, reduce energy consumption, increase pellets' durability, or are a nutrients-carrying medium – in the case of fodder, etc. This is confirmed by numerous research studies in which additives were introduced into the mixture: caustic soda and maize starch as a binder in the process of biomass densification **[Finney et al. 2009]**; caustic soda added to residue from palm oil production **[Razuan et al. 2011]**; olive pomace residue from olive oil production added to densified Pyrenean oak residue **[Miranda et al. 2012, Miranda et al. 2012A]**; industrial cork residue added to vine shoots **[Mediavilla et al. 2009]**; hydrolysis post-production residue from lignocellulosic ethanol production added to densified biomass **[Ohman et al. 2006]**; gum arabic and manihot starch in the process of densification (briquetting) of carbonized (torrefied) wood residue from forest production **[Sotannde et al. 2010]**; maize starch or lignosulfonate (a byproduct of cellulose production) in the process of pelleting of shredded poplar energy crop **[Mediavilla et al. 2012]**; shredded waste wrapping paper in the process of densification of wood waste **[Kong et al. 2012]**; post-production turnip waste from turnip oil production added to densified sawdust **[Stahl and Berghel 2011]**; rape flour, ground coffee, tree bark, and lignin powder in the production of pellets from larch and liriodendron [Ahn et al. 2014]; raw glycerol, bentonite, and lignosulfonate in the process of pelleting of wheat straw [Lu et al. 2014].

In the case of biomass fuels, binders should meet the following: anticorrosion conditions (chlorine corrosion), and low emission conditions, e.g. reduction of NOx emission in an original manner, in which case biomass pellets can be used as a medium carrier for catalysts of the combustion process. According to Carroll and Finnan [2012], pellets enhanced through the addition of an adequate binder (one that does not have a negative impact on the quality of boilers' operation and is qualitatively consistent with the requirements of EN 14961), produced from mixtures of waste biomass, have a chance to become a competition for wood pellets as a fuel used for heating and producing electric energy.

Potato pulp is this kind of binder.

The properties of potato pulp as a binder were confirmed in the performed tests, presented in **publications no. 4-no. 6**, which allowed to determine its usability as a good binder.

One of the waste materials obtained from oat seeds during the production of rolled oats and oat flour is oat bran. Unlike bran from other grains, the use of oat bran is limited to applications as a fodder material and in nutrition as a component of many diets.

As evidenced in the performed initial tests, non-shredded oat bran is characterized by a low moisture content (approx. 5-6 %), which is one of the reasons why the material has a low susceptibility to densification. The slippery oat hulls, the small amount of endosperm in bran, and the low moisture content cause the bran to be forced through matrix openings at low densifying pressures. The density of the obtained pellets is very low. Due to this oat bran should be shredded, which would lower its tendency to slide on the matrix openings, its moisture content should be increased before the process of densification, or a binder should be used. The tests presented in **publications no. 4 and 5** confirmed that an addition of potato pulp to non-shredded oat bran allowed to improve its susceptibility to densification and the possibility of its use as a raw material for pellets production (at a low moisture content) making it possible to obtain pellets of satisfactory durability properties.

Papers connected with research studies of the process of densification of oat bran have not been found in literature.

There are, however, other research studies whose authors performed densification of biomass waste with a granary waste content [Niedziółka and Szpryngiel 2012; Szlachta and Jakubowska 2013; Zawiślak et al. 2014, Angulo et al. 1995]. In these studies, the most commonly used additive (component) to the densified mixture was wheat bran.

Szlachta and Jakubowska [2013] performed the pelleting process of straw with a 10% mass wheat bran content, which confirmed the reduction of the load of the pelleting unit of the pellet mill by approx. 5% on average, at a comparable efficiency of production. Niedziółka and Szpryngiel [2012] assessed quality properties of pellets (diameter and length, heat of combustion, bulk density, kinetic durability, among others) produced from selected plant materials and their mixtures (e.g. with a wheat bran content) in a pellet mill with a one-sided immovable flat matrix. Anguloi et al. [1995] assessed the quality of fodder pellets for swine, in which wheat bran, among others, functioned as an additive with a high fiber content.

These papers, however, do not present the influence of the significant factors on the course of the densification process.

Zawiślak [Zawiślak et al. 2014] performed tests of densification of wheat bran. In his studies, he observed that the value of the densifying force in the process depends on the degree of shredding of bran. An increase of the degree of shredding results in a reduction of the forces and has a beneficial impact on the quality of the obtained product.

There are other papers available, e.g. [Robin et al. 2011; Robin et al. 2011a; Robin et al. 2011b;], in which the authors used an addition of wheat bran in the extrusion process. In his research, Robin concluded that a bran content has an impact on the viscosity of the extruded material, reduces expansion of foamed starch, and modifies water distribution between different phases.

The impact of selected factors on the course of the densification process and the quality of the obtained pellets can be found in other papers [Dziki et al. 2010; Skonecki and Laskowski 2010; 2012;

Skonecki et al. 2014; Zawiślak et al. 2010; Svihus and Gullord 2002; Zimonija and Svihus 2009], which, however, describe densification of cereal grain.

Due to the differing properties of shredded granary materials (a significantly higher susceptibility of these materials to densification, owing to their high proportion of starch and proteins), in comparison with oat bran (in which the contents of starch and proteins are much lower), it is difficult to compare the processes of pelleting of these materials.

Another waste material in the case of which good properties of potato pulp as a binder material were confirmed were buckwheat hulls, which are a residue material produced during the processing of buckwheat into groats. Numerous reports in literature [Watanabe et al. 1997; Stolarski and Kwiatkowski 2009; Chachułowa et al. 1997; Prokkola et al. 2003; Tang et al. 2003] show that although buckwheat hulls have several niche applications, they are most often considered a waste material, and buckwheat-processing companies are seeking real possibilities for their use [Stolarski and Kwiatkowski 2009].

Non-shredded buckwheat hulls are a material characterized by a low susceptibility to densification, which was confirmed in the performed initial tests, as well as in the experience of the Ekofrisa company [Janušonis et al. 2009], according to which production of pellets from buckwheat hulls is more complicated than production of pellets from the typical raw materials (e.g. sawdust), due to the fact that buckwheat hulls do not contain a binder in their composition. Therefore, in order to increase their susceptibility to densification, hulls are shredded or subjected to the action of steam prior to the densification process [Janušonis et al. 2009].

Another method for increasing the susceptibility of buckwheat hulls to densification **and** improving the conditions of implementation of the process is adding a binder to them during the densification process. This was confirmed by the performed tests of densification of buckwheat hulls with a content of potato pulp as a binder, described in **publication no. 6.**

Papers connected with research studies of the process of densification of buckwheat hulls have not been found in literature.

There are, however, research studies whose authors used buckwheat hulls as an additive to fodders [Mulholland and Preston 2001; Amelchanka et al. 2010; Préstamo et al. 2003; Deng et al. 2014; Zhu et al. 2014] or food [Li and Zahang 2001, Zhang et al. 2012; Gimenez-Bastida 2015].

In conclusion, it should be stated that the research studies presented in **publications no. 3-no. 6** confirmed that potato pulp as an additive to waste plant materials with a low moisture content (such as oat bran or buckwheat hulls) is an excellent binder allowing to increase the mixture's susceptibility to densification, which leads to a reduction of energy consumption of the pelleting process, and to obtaining pellets of satisfactory durability properties.

Densification of waste plant materials with a low moisture content with an addition of potato pulp allows to utilize a troublesome waste material, i.e. the potato pulp lying in huge heaps in the plant's grounds, at the same time allowing to obtain agglomerate (pellets, briquettes) of a higher quality, at lower energy consumption of the densification process. Apart from this, as shown in the research studies of the contents of chlorine and other elements significant in the process of combustion in potato pulp, pellets with a pulp content may become a highly attractive fuel in comparison with other types of biomass (lower contents of these elements in the pulp). Introduction of pulp during the process of densification of biomass materials such as oat bran or buckwheat hulls (and others in the future) reduces the corrosive properties of the fuel (pellets) obtained in the process of combustion. This is confirmed by other research presented in papers [Król et al. 2010; Król 2012].

The performed research studies (publications no. 3-no. 6) allowed to confirm potato pulp's usability as an excellent binder material, which is at the same time characterized by high energy properties (high values of heat of combustion and calorific value), leaving small amounts of ash residue after the process of combustion. A method for reducing the high moisture content of potato pulp is its use as an additive to other biomass waste with a low moisture content subjected to pelleting (e.g. wood dust, straw, oat bran, buckwheat hulls). The conducted tests of the process of pelleting of biomass materials with a small susceptibility to densification with a potato pulp content allowed to conclude that pulp improves their susceptibility to pelleting, reduces energy consumption, and increases pellets durability. It also makes it possible to reduce the corrosive properties of combustion devices owing to the extremely low chlorine contents.

Results of the conducted research allowed to create detailed guidelines for a technology of production of heating or fodder pellets (depending on the used components of the densified mixtures) with a potato pulp content, which resulted in the author's patent application [Obidziński 2012]:

Obidziński S.: Heating pellets and the technology of their production. Patent application P.398399 dated 12.03.2012. The Patent Office of the Republic of Poland. Warsaw 2012.

4.6. LITERATURE

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5. DESCRIPTION OF THE OTHER RESEARCH (ARTISTIC) ACHIEVEMENTS

The many years of research that I have been conducting, also including the time before I was awarded the doctoral degree, were aimed at creating concepts and guidelines for designing new prototype devices for the implementation of the processes of pressure agglomeration of plant materials, and the assessment of their quality. This activity was a continuation of my earlier designs of densifying devices (created before I was awarded the doctoral degree). One of my concepts, i.e. the design of a universal pelleting-briquetting device for plant materials was built in the Department of Food Industry Machines and Appliances (at the Faculty of Mechanics of Białystok University of Technology) and is currently used for academic activity. A detailed description of the device can be found in the following publication:

Obidziński S.: A universal stand for testing the process of pressure agglomeration of plant materials. Research Bulletins Of Białystok University of Technology. Construction and operation of machines. B. 9. Białystok 2002, pp. 325-331.

The working system of the device consists of a horizontal, immovable ring matrix (replaceable as needed – with various opening sizes or various wall thicknesses), and a set of three densification rolls mounted on a vertical shaft of the pellet mill.

The drive unit consists of a hydraulic motor, whose drive is conveyed through a gear and a torque meter (which measures the torque during device operation) to the upper shaft, on which a set of three densification rolls is mounted. Feeding of the material is realized by means of a special dosing system, rotating together with the rotation of the densification rolls. An even distribution of material into the matrix under each of the densification rolls was achieved by means of openings cut out in the feeding hopper (cone) in front of each of the three densification rolls.

My activity after having been awarded the doctoral degree was also inspired by earlier experiences (the complexity and diversity of issues present during pelleting and briquetting), whose result is that technical and technological innovations consist in finding solutions to process details with a simultaneous modernization of working systems of pelleting and briquetting devices. As part of this activity, together with colleagues, I prepared 6 patent applications:

1. **Obidziński S., Zyskowski S.:** Method and devices for assessment of kinematic durability of products of pressure agglomeration. Patent application P.391255 dated 17.05.2010. The Patent Office of the Republic of Poland. Warsaw 2010.
2. **Hejft R., Obidziński S.:** Mixing and briquetting mill for shredded plant materials. Patent application P.396292 dated 12.09.2011. The Patent Office of the Republic of Poland. Warsaw 2011.
3. **Hejft R., Obidziński S.:** Separator of material in the working system of a pellet mill. Patent application P.397576 dated 27.12.2011. The Patent Office of the Republic of Poland. Warsaw 2011.
4. **Hejft R., Obidziński S.:** Mixing, pelleting, and dosing device for the working system of a pellet mill. Patent application P.397754 dated 09.01.2012. The Patent Office of the Republic of Poland. Warsaw 2012.
5. **Obidziński S., Hejft R.:** Flat pelleting and briquetting matrix. Patent application P.397986 dated 02.02.2012. The Patent Office of the Republic of Poland. Warsaw 2012.
6. **Obidziński S., Wszeborowski D.:** The stabilizing and cooling track for briquettes. Patent application P.412055 dated 20.04.2015r. Patent Office of the Republic of Poland. Warsaw 2015.

In 2012 I participated in the MNiSW Nr N N504 488239 research project entitled **"Tests of the working system of a pellet mill for plant materials"**, in which I was the sole main executor. As part of the project implementation, on the basis of earlier experiences and own prototype designs of pellet mills in the Department of Agricultural, Food and Forestry Engineering (at the Faculty of Civil and Environmental Engineering of Białystok University of Technology), many years of research of prototypes of pellet mills with a flat matrix, an exchange of experiences with many companies producing pellet mills (with a flat and ring matrix), and an analysis of patent documentations of such devices, guidelines were created and a new prototype pellet mill was built (fig. 1). The concept of the new pelleting system (a working system with a flat immovable matrix) was based on the prepared patent applications **(no. 3, no. 4 and no. 5).**

The core of the solution for **mixing/pelleting/dosing system** 1 (fig. 1) for the working system of the pellet mill is the use of an internal rotating cylinder (encased in an immovable external cylinder), into which the material is fed. The internal cylinder is equipped with replaceable plates, mounted with screws and arranged in a helix along its length, with a possibility of adjustment of their angle. The system performs the functions of: mixing, non-pressure pelleting, and dosing of material into the working system of the pellet mill, eliminating dusty fractions, unfavourable from the point of view of the process, from the material (through their non-pressure agglomeration inside the rotating cylinder). The device is mounted in the upper part of working system 6 of the pellet mill with a flat matrix.

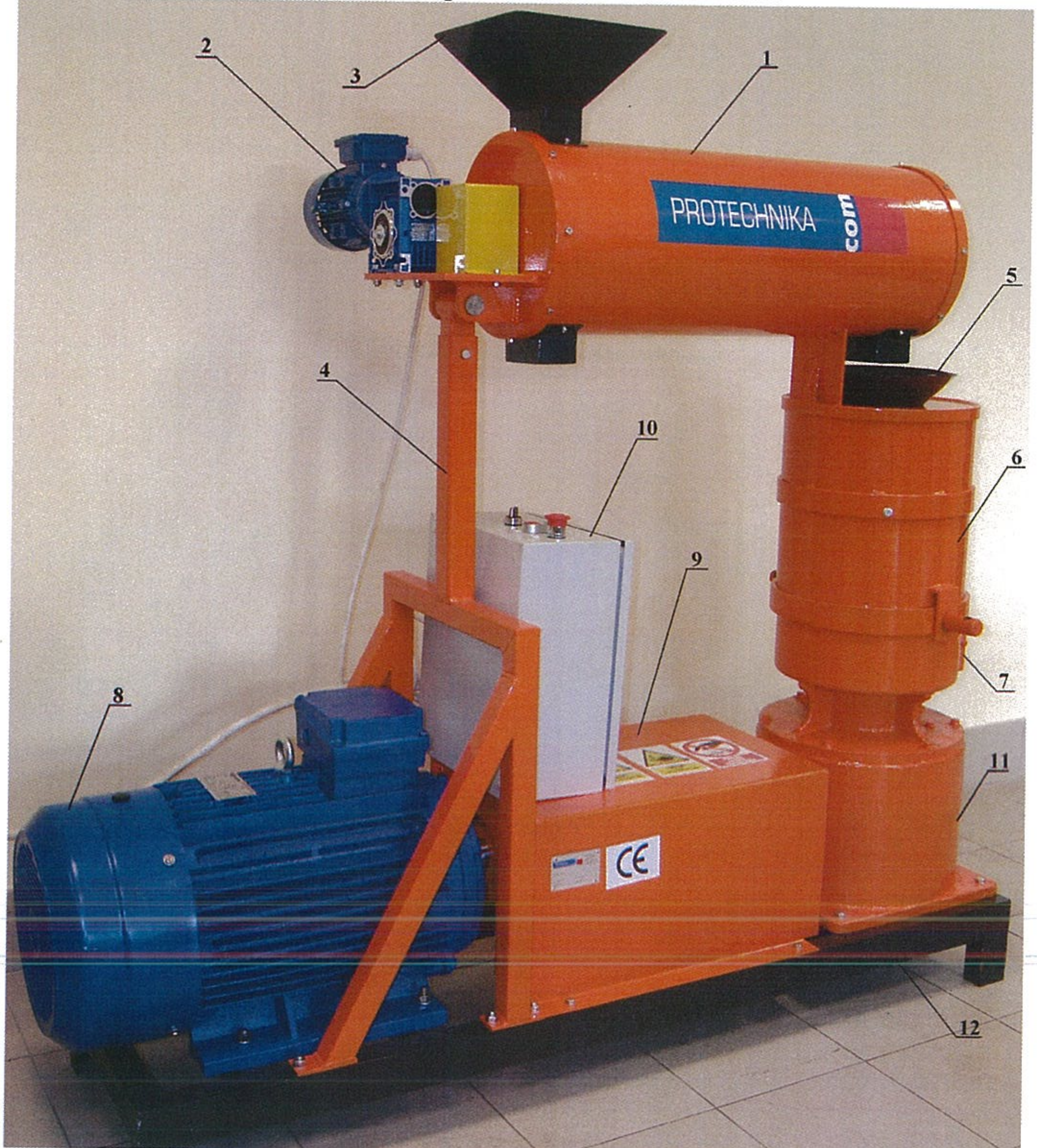

Fig. 1. View of the new pelleting and briquetting device with a flat immovable matrix: 1-mixing/pelleting/dosing system, 2-drive of the mixing/pelleting/dosing system, 3-charger of the mixing/pelleting/dosing system, 4-fixing frame of the mixing/pelleting/dosing system, 5-feeder of material to the working system of the pellet mill, 6-working system of the pellet mill, 7-outlet of pellets from the working system, 8-drive of the pellet mill (electric motor), 9-clutch shield and torque meter, 10-control panel, 11-gear, 12-base

The separator of material (fig. 2) for the working system of the pellet mill (fig. 1, pos. 6) is mounted on the shaft of the pellet mill under dosing cone 3. The core of the construction solution of the separator is the use of adjustable blinds 7, which ensure the evenness of streams of material coming under densification rolls 2. The adjustable opening of blinds' wings 7 also allows to adjust the output of the device to its nominal power, depending on the physical, chemical, and biological properties of the used material.

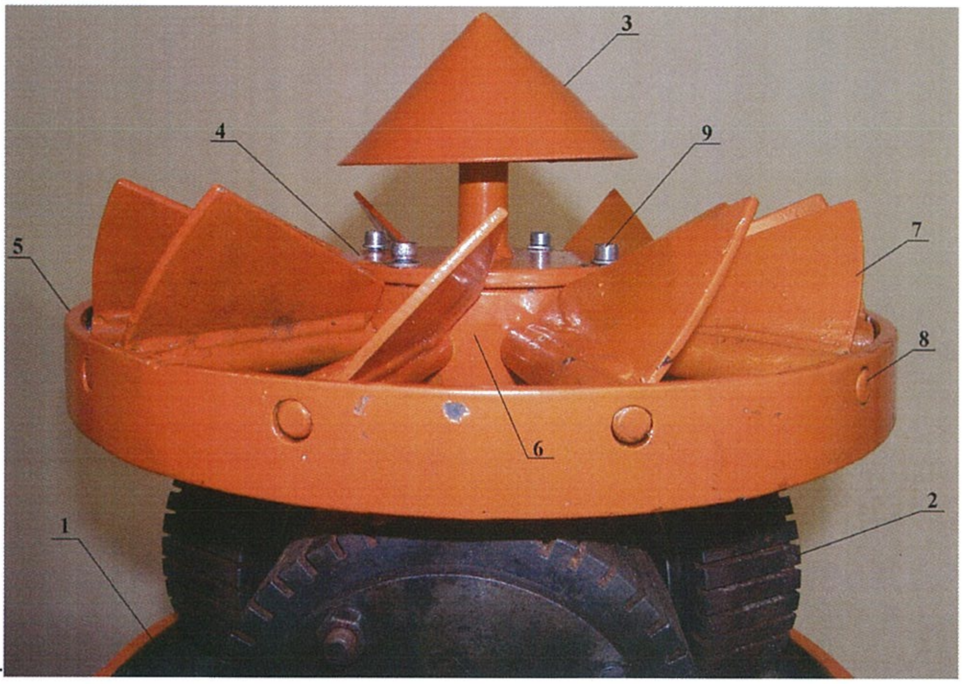

Fig. 2. The system for material separation for the working system of the pelleting and briquetting device: a) system scheme, b) view of the system (own photo): 1-flat matrix, 2-densification roll, 3-dosing cone, 4-cone-mounting shield, 5-external wing-mounting band, 6-internal wing-mounting band, 7-wing, 8-blind wing axis, 9-mounting screws

The core of the solution for the pelleting and briquetting matrix (fig. 3), used in the working system of the pellet mill (fig. 1, pos. 6), that is the subject of the application is the use of smaller openings, i.e. the so-called pelleting openings, between the openings for briquetting.

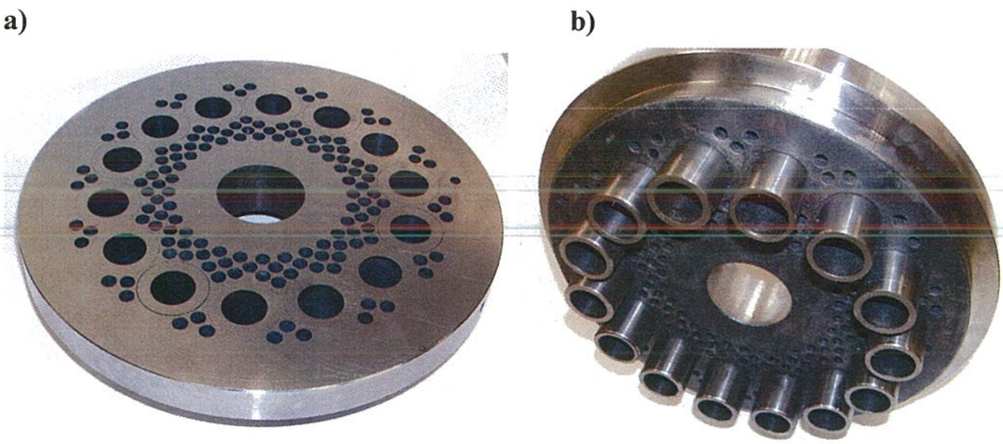

Fig. 3. View of the special pelleting and briquetting matrix: a) top, b) bottom

In previous construction solutions of flat matrices for briquetting of plant materials, there was a significant so-called dead area (over 50-60% of the working surface of the matrix) between the openings (diameters of openings of 20-30 to 50-70 mm). This has a significant impact on the increase of the energy consumption of the process and limits its efficiency. An introduction (according to patent application **no. 5**), along the circumference of the matrix (depending on the size of a row, or several rows), of its replaceable sleeves with the so-called briquetting openings and the "pelleting" openings placed between them, allows to significantly reduce the so-called dead surface (increasing the coefficient of matrix perforation), making it possible to produce both briquettes and pellets during the process, which will significantly increase (by approx. 20-30 %) the efficiency of the densification process and reduce its energy consumption.

Details of the devices that will be the subjects of patent applications **(no. 3, no. 4, and no. 5)** were also presented in the following publications:

Hejft R., Obidziński S.: Pressure agglomeration of plant materials – technological and technical innovations. Part II – The dosing, mixing, and pelleting system. Journal of Research and Applications in Agricultural Engineering, 2013, **Vol. 58**(1), Poznań 2013, pp. 60-63.

Hejft R., Obidziński S.: Pressure agglomeration of materials of plant origin – pelletizing and briquetting (part one). Journal of Research and Applications in Agricultural Engineering, 1/2014, Vol. 59(1), 44-47.

which have been made available as **Appendix V**.

As part of the implemented **MNiSW No. N N504 488239 research project entitled "Tests of the working system of a pellet mill for plant materials"**, a contractor was chosen who built the prototype of a new pelleting and briquetting system (fig. 1), on the basis of patent applications **(no. 3, no. 4, and no. 5)**, technical specifications prepared by myself and a co-author, and consultations concerning the aforementioned applications.

Details of the construction of the new prototype pelleting and briquetting system were presented in the report:

Hejft R., Obidziński S.: Tests of the working system of a pellet mill for materials of plant origin. Content report from the implementation of an own research project no. N N504 488239 (contract number 4882/B/T02/2010/39). Białystok, November 2013.

Concepts of other devices for the implementation of the process of pressure agglomeration of materials with an increased moisture content, in which I co-authored the devices, i.e. the mixing and briquetting device for shredded plant material and the mixing, densifying, and dosing system of the pellet mill, are presented in the following publications:

Hejft R., Obidziński S.: Agglomeration of waste materials of plant origin with an increased moisture content. MOTROL,Vol. 14, No. 5, ISSN 1730-8658, Lublin-Rzeszów 2012, pp. 177-182.

Obidziński S., Hejft R.: Construction of a mixing/densifying/dosing pellet mill for plant materials. Agricultural engineering, B. 1(141) Vol. 1. Kraków 2013, pp. 143-148.

which have been made available as **Appendix V**.

The mixing and briquetting device for shredded plant materials consists of a cylindrical mixing chamber, in which a multi-turn mixer is placed (e.g. frame, anchor, blade), which ends with a densifying worm working with a densifying sleeve (mounted on the base of the device) in the bottom part of the mixing chamber. The device enables a compromise solution for mixing a material with a high moisture content with a dry one. The high moisture content of one of the materials will cause a mechanism of particle binding (also dry material) through liquid bridges to commence. Due to the fact that there is a large number of particles smaller than 1 mm in a shredded plant material (depending on the method of shredding and the type of plant material, e.g. sawdust, straw, this value can be estimated at a level of several to twenty per cent), this fraction undergoes non-pressure agglomeration through coating during the mixing, creating initially densified, many times larger agglomerates. The average moisture content of the moist and the dry materials, depending on their proportions, may enable a further processing of a powdery material into a solid fuel in the form of briquettes. Considering that waste plant material, e.g. sawdust, is often characterized by a high moisture content (approx. 40-50%), presented was the possibility of using mechanisms of non-pressure densification started during the mixing of the two materials in the mixing chamber prior to the process of pressure agglomeration, which begins the moment the opening/closing mechanism opens. The presented method of briquetting of shredded plant materials allows to reduce energy consumption (connected with drying and densification) in the production of solid, ecological fuel from plant waste.

The mixing/densifying/dosing system of the pellet mill allows to eliminate the most fine-grained fractions of the shredded plant material (subjected to pelleting) through its non-pressure pelleting during mixing. This also enables initial densification and controlled dosing of the plant material fed to the working system of the pellet mill, which has an influence on the quality of pellets and the energy consumption of the process. Plant materials are fed to the mixing chamber, where they are mixed with the use of two ribbon/worm mixers. The mixed plant material is then initially densified by means of a conical worm wound on the mixing shaft, working with the conical screen of the mixing chamber. The initial pressure densification of the material is controlled by means of the size of the gap between the conical screen and the dosing cone for the densifying system of the pellet mill. The initially densified plant material is fed through the conical worm through the dosing gap and falls under densification rolls 8, which roll it to the openings of the pellet mill's matrix, in which it is densified.

The concept for the new **universal device and method for the assessment of kinetic durability of products of pressure agglomeration** was presented in the following patent application:

Obidziński S., Zyskowski S.: Method and device for the assessment of kinetic durability of products of pressure agglomeration. Patent application P.391255 dated 17.05.2010. The Patent Office of the Republic of Poland. Warsaw 2010.

In the proposed concept, it was decided that replaceable test chambers allowing to combine Pfost's and Holmen's methods for the assessment of kinetic durability of pellets with the method for the assessment of kinetic durability of briquettes pursuant to GOST-18691-73 and ASAE S.269-1A in a single device would be used. Using an air blower and perforated walls of test chambers increases test aggressiveness and allows to let the shredded particles out of the chamber. The use of special guides and frames in the chamber, made from bars with special levelling feet allows to adjust the size of the chamber to the selected method. Details of the universal device and the method for the assessment of the kinetic durability of products of pressure agglomeration were also presented in the publication:

Obidziński S., Zyskowski S., Miastkowski K., Joka M., (2015). An universal device for the assessment of the kinetic durability of products of pressure agglomeration. Journal of Research and Applications in Agricultural Engineering", 1/2015.

Among my achievements connected with creating concepts and guidelines for the construction of new devices **are**:

- designing and building a range of research and educational test stands,
- the design of a worm feeder for plant materials, built in the Department of Food Industry Machines and Appliances, and currently used for research and educational activity,
- preparing a detailed technical concept for the construction of a worm feeder for plant materials, built by *Hydrapress Sp. z o.o.* in Bydgoszcz in 2012, and currently used for research and educational activity.

Another direction of my scientific activity was the implementation of potato pulp as a raw material for the production of solid fuels. My interest in potato pulp stemmed from the fact that it is produced in Poland in huge amounts. Tests allowing to create the concept and technology for the production of a new fuel with potato pulp added to other types of the so-called non-forest biomass were performed as part of the following research project, among others:

Obidziński S. et al. (2008). Tests and creation of the concept and technology for a new fuel from non-forest biomass with the use of grasses, carex, reeds, and shrubs from the area of Narew National Park; sunroot, energy poplar, and the common sunflower from planters; and tests of potato pulp from Pepees S.A. Own research project of Łomża State University of Applied Sciences. Łomża 2008.

in which I took active part, performing tests of energy properties of pulp and co-authoring the final report of the project.

Tests of energy properties pf potato pulp I also presented in the following publication:

Obidziński S.: Assessment of the energy properties of potato pulp. Postępy Techniki Przetwórstwa Spożywczego. No. 1(2010). Wydawnictwa Wyższej Szkoły Menadżerskiej w Warszawie. Warsaw 2010. pp. 58-62.

The conducted tests show that potato pulp is a raw material of high energy properties. Its heat of combustion in the dry state is 16.33 MJ/kg, while the calorific value is 15.41 MJ/kg. It is, however, a material of a very high moisture content, often exceeding 88 %, which is a serious issue as far as its use as a raw material for the production of solid fuels is concerned. One of the methods for extending the shelf life of potato pulp for use or applications as an additive to other plant materials in the densification process is mechanical dehydration (used also due to the significantly lower energy consumption during process implementation, in comparison with the process of thermal drying). The use of mechanically dehydrated pulp allows to increase the proportion of pulp content in a mixture of biomass materials densified for energetic purposes. Tests connected with the process of mechanical dehydration of potato pulp I presented in the following publications:

Obidziński S., Szulc K.: Tests of the process of mechanical dehydration of potato pulp. Postępy Techniki Przetwórstwa Spożywczego. Wydawnictwa Wyższej Szkoły Menadżerskiej w Warszawie. No. 1/2014, 77-83. ISSN 0867-793X.

Obidziński S., Kostrzewska K.: The influence of the mass of a dehydrated sample and the pressure of the piston on the process of dehydration of potato pulp. Chapter in a monograph edited by Jerzy Jaroszewicz: "Energy in science and technology 2014". Oficyna Wydawnicza Politechniki Białostockiej. Białystok-Kleosin 2014, pp. 141-152.

in which I was the author of the concepts of the performed tests, analyzed their results, and then prepared publications on their basis.

The process of mechanical dehydration of potato pulp was implemented with the use of a hydraulic press and a purpose-built dehydrating system "dehydrating piston – chamber – matrix" placed between the upper and lower pistons of the press. In the papers, determined were the influences of a dehydrated sample and piston pressure on its degree of dehydration and the reduction of moisture content after the process of pressing. In the course of the tests, it was observed that dehydrated pulp, subjected to the process of drying for 24 hours in a temperature of approx. 20°C, reduces its moisture content by approx. 42-49% (depending on the dehydration parameters), in comparison with the moisture content after dehydration. Non-dehydrated pulp, on the other hand, after the same time (after 24 hours in a temperature of 20 °C) reduces its moisture content by as little as approx. 22 %. The increased reduction of moisture from dehydrated pulp is connected with changes in the structure of particles of the dehydrated pulp, which occur during dehydration under the pressure of the dehydrating piston. The altered structure leads to a faster migration of water from such particles to the environment. This is a very positive information from the point of view of its further utilization.

On the basis of the performed tests connected with mechanical dehydration of potato pulp, the following patent application was created:

Obidziński S., Łapiński A.: A dehydrating, shredding, and dosing system for materials with a high moisture content. Patent application P.409639 dated 29.09.2014. The Patent Office of the Republic of Poland. Warsaw 2014.

in which I was the main author of the device's concept.

The core of the solution for the dehydrating device is a specially-designed sleeve, consisting of a body, in which a specially-designed half-cylindrical dehydrating sieve works with a filter and a filter press in the form of another half-cylindrical sieve. The dehydrated material is moved, by means of a worm, along the dehydrating sieve. During the material's movement, the space between the sieve and the core of the worm is reduced, resulting in liquid being squeezed from the material. The squeezed liquid flows through the openings in the bottom part of the half-cylindrical sieve. The sieve and a knife mounted at the end of the dehydrating sleeve make it possible for the device to perform the operations of dehydration, shredding, and dosing, e.g. to the mixing system of a densifying device. Efficiency of the operations of dehydration and shredding can be controlled by changing the rotational speed of the worm.

6. SUMMARY OF SCIENTIFIC ACHIEVEMENTS

The results of the research I conducted after having been awarded the doctoral degree, connected mostly with my **scientific interests in the process of densification of plant materials with the aim of their use as a fodder or a solid fuel in the form of pellets or briquettes** was the publication of **69 scientific publications (including those that constitute the scientific achievement)**, of which 4 are independent publications indexed in the Journal Citation Reports (JCR) database, with an Impact Factor. The remaining 65 publications are papers in the form of: 40 articles in scientific journals from the MNiSW list of high impact journals, 14 chapters in monographs (including two in English), 7 articles published in conference materials, and 4 publications in journals not on the MNiSW list of high impact journals. I am the sole author of 23 of these publications, and a significantly contributing co-author of the rest of them.

A synthetic summary of my publishing achievements after being awarded the doctoral degree is presented in table 2.

Table 2. Summary of publishing achievements after being awarded the doctoral degree

Type of publication	Number	Points awarded
Indexed articles in the Journal Citation Reports (JCR) database, with an Impact Factor	4	92
Articles in scientific journals on the MNiSW list of high impact journals	43	228
Other articles, not on the MNiSW list of high impact journals	4	0
Articles published in conference materials	7	4
Monograph chapters in Polish	12	59
Monograph chapters in English	2	10
TOTAL	**72**	**393**

The total number of points for the publications so far, according to the normalized MNiSW list for 2012 is **393 points**; after subtracting the point for the monograph series of publications comprising the habilitation achievement the number is **288 points**.

Currently a further 5 publications of mine are being printed or reviewed.

I am also a co-author of one patent and the author of **8 patent applications**.

In the course of my academic work, I have taken part in 15 research projects financed from KBN and MNiSW, in which I was Head of the Project (in 2 projects), and the main executor in 5; as well as in 7 projects co-financed from the European Union. Three of the research projects I participated in were KBN and MNiSW grants, in which I was the main executor.

I was also the author or co-author of **74 reports (lectures and posters)** at international and national thematic conferences, of which **49** were **reports** after I had been awarded the degree of PhD in technology.

Białystok, date 04.05.2015