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PHYSICOCHEMICAL AND MICROBIOLOGICAL CHARACTERISTICS OF PIG SLURRY

FIZYKOCHEMICZNA I MIKROBIOLOGICZNA CHARAKTERYSTYKA GNOJOWICY ŚWIŃSKIEJ

A b s t r a c t

Pig slurry is classified as a natural fertilizer of animal origin, being a mixture of faeces, urine, remains of fodder and water used for the elimination of faeces. It is generated in non-bedding pig farming conditions, where animals are kept on slatted floors (grate or slotted floor). This paper presents the general characteristics of pig slurry, its physicochemical properties and its microbiological composition. Also, factors affecting slurry properties are discussed.

Keywords: *pig slurry*, *physicochemical properties*, *microbiological composition*, *fertilizing components*

S t r e s z c z e n i e

Gnojowica świńska klasyfikowana jest jako nawóz naturalny pochodzenia zwierzęcego będący mieszaniną kału, moczu, resztek paszy oraz wody stosowanej do usuwania odchodów. Powstaje ona w warunkach bezściółkowego chowu trzody chlewnej, w którym zwierzęta utrzymywane są na podłogach ażurowych (szczelinowych lub rusztowych). W niniejszym artykule przedstawiono ogólną charakterystykę gnojowicy świńskiej, jej właściwości fizykochemiczne oraz skład mikrobiologiczny. Omówiono także czynniki wpływające na właściwości gnojowicy.

Słowa kluczowe: *gnojowica świńska*, *właściwości fizykochemiczne*, *skład mikrobiologiczny*, *składniki nawozowe*

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1. Introduction

Slurry is liquid agricultural waste generated in the non-bedding method of pig farming, it is a mixture of animal excrements and technological water used for sanitary purposes in livestock housing. The non-bedding system of pig farming, the development of which commenced in Poland in the early 1970s, results in large volumes of slurry which must be appropriately managed [1–3]. According to the Act on Fertilizers and Fertilization [4], slurry is a natural fertilizer. Therefore, its use for agricultural purposes is most appropriate from the point of view of environment protection and it is also the most economically justifiable option [1–6]. It must, however, be stressed that irrational or excess fertilization with slurry can contribute to the contamination of the natural environment, particularly in areas with a high concentration of pig farms and a deficit of agricultural fields where slurry can be applied. Slurry can be a source of odour nuisance and can contaminate the air with ammonia and greenhouse gases (methane, carbon dioxide, nitrogen oxide (I) and hydrogen sulphide). Slurry can also cause the leaching of fertilizing components into groundwater, the eutrophication of surface waters, as well as soil degradation due to supersaturation with phosphates or acidification with ammonia. Furthermore, in the case of either a lack of or improper hygienization methods, slurry can cause a potential sanitary-epidemiological threat due to the spread of pathogenic bacteria in the environment [7–10].

2. Non-bedding system of pig farming

During recent decades, interest in non-bedding pig farming has been growing among farmers. This is where animals are kept on slatted floors (slotted and grate floors) or partially--slotted floors (partially-grated floors) and where part of the floor is full, and some is in slat form. The choice of this raising system is usually related to a lack of sufficient volume of bedding materials (straw), the opportunity of reducing human labour and the easier elimination of excrements and keeping livestock housing clean. Furthermore, the system allows for effective disinfection of the pigsty, owing to which, it assures high hygienic standard and thus reduces the opportunity for the spread of disease. Slatted floors must be made of appropriate materials (plastic, concrete, metal, glass-fibre) and must be characterised with optimally selected beam widths and slots in order to limit damage to animal feet and to ensure easy permeation of faeces to channels made under the floor where faeces can be stored and via which they flow, or from which they are pumped into tanks outside the pigsty. Due to higher investment costs (as compared to bedding systems), non-bedding systems are more frequently applied in large industrial farms than in individual farms. In Poland, most large farms, built both in the 1970s and in the last decade, apply non-bedding systems. Despite many advantages, non-bedding technologies are often criticised. The criticism is principally related to the problem of the correct storage, management and utilization of the slurry [1, 11–13].

3. General characteristics of pig slurry

Pig slurry is a mixture of: faeces and urine in the natural ratio, which approximately amounts to 40% faeces and 60% urine; water used for keeping the pigsty clean (animal washing, station cleaning, channel flushing); remains of fodder. Faeces contain undigested, digested and unabsorbed parts of fodder, raw fibre, cellulose, woody parts, parts of plants in various degree of decomposition, mineral materials, water, excretions from the digestive system, as well as bacteria and products of their metabolism. Urine is a water solution of various organic and inorganic substances, including nitrogen compounds from the metabolism of protein and non-protein substances containing nitrogen, as well as vitamins, hormones and enzymes. The proportion of water in slurry should not exceed 20% in relation to the volume of excrements as production of very diluted slurry (e.g. due to uncontrolled or excess water consumption at the farm) generates costs related to the storage, transportation and management of the slurry in a manner safe for the environment [1–3, 7]. It is generally adopted that slurry containing up to 6–8% dry matter is classified as diluted, while over 6–8% as dense. The slurry produced in a typical Polish breeding farm differs from slurry generated in farms in other countries. Usually, slurry from Polish farms is characterised by its lower dry matter content. By type, slurry can be divided into complete and incomplete. Complete slurry does not contain addition of liquid manure (which is fermented urine from bedding stations of animals with small addition of water and manure water, namely leachate from farmyard manure) and other wastewater. Incomplete slurry can contain liquid manure and wastewater or one of these admixtures [1–3, 11, 14].

The volume of slurry generated in a farm depends on the size of livestock, the purpose of animal raising, and the intensity of feeding, which affects the volume of excrement and the volume of water consumed. It is assumed that the volume of faeces and urine per one livestock unit (1 LU – reference unit for aggregation of livestock in a farm, corresponding to an animal with bodyweight of 500 kg or several animals with total body weight of 500 kg) amounts to 45 kg per day, on average. Normative consumption of technological water in livestock building must not exceed 10 dm^3 per day. Therefore, daily production of slurry per 1 LU amounts to approximately 55 kg (mass density of slurry = 1 kg/dm^3) [1, 2, 15].

Slurry is a polydispersive system, the solid phase of which with various degree of stratification occurs in the form of suspension (macroflocs and colloidal), or in the dispersed form as molecular solutions. Due to such a composition and the fermentation process occurring in the slurry, and as their result the phenomena of flotation and sedimentation, pig slurry containing up to 8% dry matter is stratified into three fractions: surface (scum); medium (liquid, most diluted layer, contains the least solid particles); bottom (the most visible layer, with a high share of mineral parts). Particular layers differ with the content of dry matter and fertilizing components, hence before transporting the slurry to the fields, it must be carefully mixed so as to achieve a homogeneous fertilizer and to introduce the same amount of nutrients to the soil for plants [1–3, 6, 11, 15]. The size of solid fraction particles in the slurry varies widely from several angstroms to 100 millimetres. About 45% of dry matter includes particles with dimensions from 0.2 to 0.5 mm, which largely comprise parts of faeces and the remains of undigested fodder. Over 50% of solid particles are smaller than 50 μm, whereas a significant portion is attributable to colloidal fraction. The finest colloidal particles in the solid fraction of the slurry constitute from 9 to 30%. Colloids form the smallest parts of faeces, dead and live microorganisms, mucous substances, humic acids and other materials [11].

4. Physicochemical properties of pig slurry

The following have a material impact on the physical properties of pig slurry: quantity and quality of organic and inorganic substances in faeces; water content; storage conditions, such as temperature and access to air; biological-chemical and fermentation processes taking place in the slurry [11, 14]. Properties of diluted slurry are similar to properties of liquids, while of dense slurry, the properties are similar to a plastic substance. The liquid limit of slurry is rather low and remains within the range of 5–10 Pa. Slurry can be treated as a Newtonian fluid if it contains up to 5% dry matter [3, 14]. The viscosity of slurry increases with the increase of dry matter content. The density of slurry ranges from 0.9 to 1.1 g/cm^3, whereas for calculations, it is assumed that slurry density is such as water density, namely 1 g/cm^3. The lower the specific heat of slurry, the higher the dry matter content in the slurry. The freezing point of slurry is around –2°C, and it decreases with an increasing content of urine and a decreasing amount of water. The freezing and defrosting of dense slurry occurs faster than in the case of diluted slurry as dense slurry has a lower specific heat. The electric conductivity of slurry is rather high and increases with an increasing dry matter content [3, 14].

In the aspect of chemical composition, slurry is not a uniform material. The chemical composition of slurry varies. This depends on many factors, such as the type and the age of animals (Table 1), their feeding system and maintenance, the quality of fodder, as well as the dilution of the slurry and its storage method. The greatest impact on the concentration of particular elements and chemical compounds in the slurry is from its dilution with water. The more diluted the slurry, the less the quantity of chemical compounds it contains. Another important factor is the method (temperature, tank parameters, frequency of homogenisation) and duration of slurry storage. During storage, losses occur principally in the aspect of organic matter and nitrogen. The volume of such losses for dry matter remains within the range of 4–16%, while for nitrogen, at a level of around 8% [1, 11, 14, 15].

Pig slurry is characterised by a high degree of hydration, on average containing 6–8% dry matter, whereas about 70–80% of dry matter comprises organic materials. Indirect ratios that can point to the amount of organic matter in the slurry include BOD_5 (five days' biochemical oxygen demand), COD (chemical oxygen demand) and TOC (total organic carbon). The biochemical oxygen demand of the slurry is difficult to precisely determine as slurry is a substance subject to continuous dynamic biological and chemical changes. Due to the domination of chemical transformations in slurry, a more reliable assessment of its organic matter content can be obtained through COD determination. The parameter defines the content of organic compounds, both undergoing and not undergoing biological decomposition. However, the best indirect ratio of organic compounds in the slurry is deemed as total organic carbon content [3, 5, 11, 14, 16]. Studies by many authors [3, 5, 11, 16–18] revealed that pig slurry is characterised by a very high biochemical oxygen demand and a rather high chemical oxygen demand (Table 2). The reaction of typical pig slurry is usually slightly alkaline (Table 2) [5, 11, 17–21].

Table 1

Impact of type and age of animals on physicochemical composition of pig slurry (average content in % of fresh matter) acc. to [11, 14]

Parameter	Piglets	Weaners	Sows	Finishers
Dry matter	1.27	3.95	4.95	8.62
Organic dry matter	0.85	2.98	3.76	6.37
Mineral dry matter	0.42	0.97	1.19	2.25
Total carbon	0.47	1.72	2.00	3.35
Total nitrogen	0.20	0.40	0.43	0.57
Ammonium nitrogen	0.16	0.25	0.24	0.27
Phosphorus	0.02	0.07	0.10	0.12
Potassium	0.12	0.16	0.17	0.36
Calcium	0.03	0.11	0.20	0.20
Magnesium	0.02	0.04	0.04	0.05
Sodium	0.03	0.03	0.04	0.06

Table 2

Comparison of physicochemical parameters of pig slurry from various countries

Parameter	Poland [5]	Poland [16]	Denmark [17]	Spain [18]	Spain [19]	Canada [20]	Russia [21]
pH	7.29	8.11	7.09	7.43	7.80	7.48	7.05
Dry matter [%]	2.30	3.80	–	–	1.29	4.05	1.25
COD [mgO_2/dm^3]	62800	47820	70000	31600	16613	–	14000
BOD_5 [mgO_2/dm^3]	17500	20250	–	14200	5000	–	–
N-NH_4^+ [mg/dm^3]	5700	1204	4800	2010	1767	4625	470
P-PO_4^{3-} [mg/dm^3]	724	–	400	–	–	–	190
P_{total} [mg/dm^3]	–	255	1600	760	–	1335	220
N_{total} [mg/dm^3]	–	1363	5600	–	–	–	760

Slurry is an important source of fertilizing macrocomponents (Table 3), which can be used for agricultural production as pig excrements contain from 70 to 80% of nitrogen and phosphorus, and from 70 to 95% potassium and calcium, contained in fodder for animals. Phosphorus is almost entirely excreted in faeces, while most potassium, in urine. Nitrogen in slurry occurs in organic combinations (proteins, amino-acids, urea, uric acid, hippuric acid) and mineral combinations (ammonia, nitrates). About 50–60% nitrogen in pig slurry occurs in the form of easily soluble ammonia nitrogen used by plants, but during slurry storage, as a result of nitrification process, NH_4^+ volume can increase to even 70% of the total nitrogen. Most frequently, slurry nitrogen covers 50–75% of the demand of plants for this component while the rest is supplemented with mineral fertilizers. Phosphorus, similarly to nitrogen, occurs in the slurry in inorganic compounds (over 40%) and organic compounds (proteins, nucleotides, phospholipids, esters), whereas over 35% of phosphorus is in the form of easily soluble compounds, while 48% is in the form of hydrolysing compounds. Over 90% of the total potassium contained in slurry can be diluted in water, hence this component is largely absorbed by plants. The content of magnesium, calcium and sodium in slurry usually meets the demand of plants for such elements [3, 11, 14].

Table 3

Fertilizing component content in pig slurry depending on dry matter content acc. to [15]

Dry matter content [%]	Content in [%] of fresh matter				
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Below 2	0.19	0.04	0.11	0.06	0.01
2.1–4.0	0.29	0.07	0.14	0.06	0.02
4.1–6.0	0.29	0.08	0.10	0.09	0.02
6.1–8.0	0.29	0.07	0.14	0.08	0.02
8.1–10.0	0.41	0.15	0.19	0.13	0.04
10.1–12.0	0.53	0.15	0.25	0.13	0.02
Over 12	0.56	0.23	0.28	0.24	0.04

Pig slurry is also rich in microelements: iron; boron; zinc; manganese; copper; molybdenum; cobalt; selenium; while the volume of heavy metals (lead, cadmium, mercury, arsenic) does not create a risk to the natural environment (Table 4). Table 4 indicates that the microelement occurring in slurry in the largest quantities is iron, while selenium is present in the smallest quantities [1, 2, 11, 22]. Slurry is a natural fertilizer containing all nutrients necessary for the correct growth and development of plants. It is a quick-acting fertilizer, comparable to mineral fertilizers in this aspect. It must, however, be remembered that the maximum dose of natural fertilizer applied during the year cannot exceed 170 kg of nitrogen per 1 hectare of farming land, which corresponds to 45 m^3 of slurry per hectare. Slurry used as fertilizer contains on average 8% dry matter and applied for example at a dose of 10 m^3/ha provides the soil with 64 kg of nitrogen, 40 kg of phosphorus and 30 kg of potassium [11, 23, 24].

Slurry is also a source of emission to the air of ammonia, greenhouse gases (methane, carbon dioxide, nitrogen oxide (I), hydrogen sulphide) and odorants. Due to the anaerobic decomposition of organic matter in the slurry occurring during its storage, gas products are emitted to the air, such as ammonia, methane, carbon dioxide, hydrogen sulphide and nitrous oxide. Also, about 400 volatile organic and inorganic compounds are released of high odour nuisance, these occur due to chemical reactions and the activity of micro-organisms. Substances responsible for odour formation can be classified into four main groups: volatile sulphur-containing compounds; indoles and phenols; volatile fatty acids; ammonia and volatile amines. Among the most important odorants causing the unpleasant odour of slurry, there are ammonia, hydrogen sulphide, diacetyl, p-cresol, indoles, phenols, mercaptans, amino mercaptans, skatoles, amines and methyl sulphides [1, 2, 7, 11, 24–28].

Table 4

Average content of microelements and heavy metals in pig slurry acc. to [1, 2]

Element	Content [mg/kg dry matter]
iron	1315.00
zinc	328.60
manganese	175.00
copper	104.00
boron	36.00
molybdenum	1.35
cobalt	0.90
selenium	0.21
lead	5.80
cadmium	0.62
arsenic	< 0.20
mercury	< 0.03

5. Microbiological composition and biological properties of pig slurry

The microbiological composition of pig slurry is varied and its clear determination is thus difficult. Slurry is characterised by a high level of bacterial population, it can contain saprophytic microorganisms, pathogenic bacteria, viruses and fungi, as well as eggs and oocysts of gastro-intestinal parasites [11, 29, 30]. In slurry, there can be micro-organisms excreted by animals together with faeces, urine, milk, blood, purulent discharges, nasal and throat discharges, as well as discharges from vaginal tracts and amniotic fluid.

Most bacteria forming part of slurry microflora include anaerobic bacteria and facultative anaerobic bacteria. The level of aerobic bacteria in slurry is rather low. The prevailing population is formed by bacteria from the Enterobacteriaceae family (Gram-negative intestinal bacteria in the shape of rod, facultative anaerobes) and the Streptococcus family (streptococci – type of spherical Gram-positive, aerobic or facultative anaerobic bacteria) [25, 30]. From slurry, one can also isolate bacteria of the Peptostreptococcus genus (Gram-positive anaerobic bacteria), the Lactobacillus genus (type of rod-shaped Gram-positive, anaerobic bacteria), the Clostridium genus (Gram-positive, obligate anaerobic bacteria of rod shape), the Enterococcus genus (enterococci – Gram-positive, facultative anaerobic cocci), the Escherichia genus (Gram-negative bacteria of rod shape, facultative anaerobes), and the Bacteroides genus (Gram-negative bacillus bacteria, facultative anaerobes) [25, 30–32]. In slurry, there can also be bacteria of the following genera: Salmonella (type of rod-shaped

Gram-negative, facultative anaerobic bacteria); Brucella (Gram-negative bacilli, causing contagious disease – brucellosis); Mycobacterium (Gram-positive aerobic bacteria of bacillus shape); Rickettsia (Gram-negative bacteria that can present as cocci, rods or thread--like) [11, 16, 29, 30, 33].

The use of slurry as fertilizer can cause the spread of parasite diseases due to its risk of contaminating with invasive forms of parasites, such as: Eimeria; Trichuris; Moniezia; Fasciola; Ascaris [11, 33]. An important issue is also the presence of antibiotics and other medical preparations in the slurry, which broad therapeutic and prophylactic use in animal breeding causes contamination of waters and soil with pharmaceuticals, as well as the formation of dangerous, antibiotic resistant strains of micro-organisms that are transferred to the environment [7, 33]. Fertilization with slurry that has not been subjected to appropriate hygienization processes and contains bacteria resistant to antibiotics can be a source of transfer of genes of antibiotic resistance to other micro-organisms present in soil [30, 33].

Despite the fact that pathogenic forms constitute a small percentage of the entire microflora present in slurry, due to their high resistance to environmental factors and their possibility of contaminating water, their contribution to the spread of many diseases can be significant. This is encouraged by the physicochemical properties of slurry, which is not subject to the process of self-heating, and in the absence of conditioning processes, can cause the microbiological contamination of soil, waters, and plants. It must be stressed that the appropriate storage of slurry before its use for agricultural purposes is very important due to a lack of opportunity for its self-heating and the risk of proliferation of some microbes in the early phase of storage [30, 33]. The activity period of bacteria, viruses, fungi, and parasites in the stored slurry highly varies and depends on the type of slurry, the species of micro-organism, and ambient temperature. Eggs of parasites can be invasive during periods lasting from several days up to a year, while viral pathogenicity can range from 70 to 300 days [29, 33]. According to the data [1], at a temperature of 8°C, eggs of Ascaris suum (large roundworm of pigs) have a lifespan of 85 days, while adult proglottids of Taenia solium (also called the pork tapeworm) have a lifespan of 76 days. Available literature also indicates that most pathogens of the Salmonella genus order undergo reduction during slurry storage (Table 5). The gradual elimination of bacteria is due to the temperature conditions, the presence of autochthonous micro-organisms and the content of nutrients. Longer survival of Salmonella bacilli in pig slurry was evident at a temperature of 4°C as compared to a temperature of 20°C, and in slurry containing above 5% of dry matter. The shorter survival of bacteria analysed at higher temperatures is explained by the fact that natural microflora develops stronger, this has an antagonistic effect on the pathogenic micro-organisms of the Salmonella genus [16, 29, 30].

Micro-organisms introduced to the soil together with slurry are subject to the impact of various factors, the most important are: soil reaction, organic matter content, temperature and moisture relations in soil. The thermal requirements of faecal micro-organisms do not allow for permanent occupation of the soil environment, although within a short period from when slurry is applied to agricultural fields, the bacteria can proliferate in soil. Finally, however, they undergo a partial or complete elimination from the soil environment. The pace of faecal microbe death in the soil environment varies. According to literature, bacteria survival time can range from several days to even up to several years. Longer survival is usually found in winter, although alternating periods of freezing and thawing contribute to decreases in the micro-organism population size. In soils rich with organic matter with rich indigenous soil microflora, micro-organisms introduced with slurry can undergo rapid elimination due to high competition for nutrients, and the presence of matter, faecal bacteria populations can also undergo a rapid reduction due to competition for nutrients with autochthonous micro-organisms [29, 30, 33].

Table 5

Survival of selected Salmonella bacilli in the stored pig slurry (pH = 7.5 – 8.0) under natural conditions acc. to [29]

Salmonella bacilli	Survival (days)
Salmonella dublin	39
Salmonella typhimurium	39
Salmonella partayphi B	39
Salmonella anatum	47
Salmonella manchester	47

A very serious threat to the environment causes irrational, too intensive fertilization with slurry. The application of excessive doses of slurry, particularly in cases where it has not been subjected to any hygienization processes, can lead to a distorted capacity for soil self-purification and the spread of parasitic diseases. Literature indicates that Ascaris eggs can preserve their invasive nature in soil for up to around two years, while their presence on plants was observed for several months. Infections of humans and animals can be due to the consuming of plants from fields generously fertilized with animal waste, as viruses and bacteria can penetrate into the root systems and stems of the plants, which points to a possibility of internal and external contamination of plants with pathogenic micro--organisms [29, 30, 33]. Due to the possible risk to the health of humans and animals, it is very important to appropriately prepare slurry for its use in agriculture. Processes of initial hygienization of slurry, which lead to a reduced number of microbes can include, for example, aeration, anaerobic digestion, or the biological treatment of slurry with the activated sludge method [11, 30, 33].

6. Conclusions

Pig slurry is a liquid waste product generated in non-bedding pig farming systems. It constitutes a mixture of faeces, urine, the remains of food and water used for sanitary and cleaning purposes. The chemical composition of pig slurry varies and depends on many factors. A major impact on the concentration of particular elements and chemical compounds in slurry is from its dilution with water. The more diluted the slurry, the less chemical compounds it contains. Typical pig slurry is characterised by a slightly alkaline reaction, a high degree of hydration, and a high chemical and biochemical oxygen demand. Slurry is a material rich with fertilizing macrocomponents (nitrogen, phosphorus, potassium, calcium), and microelements, necessary for correct plant growth, hence its most appropriate and most rational management should be related to its use for agro-technical purposes as natural fertilizer. Among the factors limiting the agricultural usage of slurry is its sanitary-epidemiological aspect. Due to its rich microbiological content (bacteria, viruses, eggs and oocysts of parasites), slurry can be a source of pathogenic micro-organism spread in the environment. However, based on the results of the studies presented in many literature items, one can state that the appropriate application of slurry, in line with the requirements of agricultural engineering, and the observation of principles relating to hygiene, does not pose a microbiological risk of contamination to waters and soils with pathogens.

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