LABORATORY DETERMINATION OF REFLECTANCE COEFFICIENT SELECTED FOR THE BEDDING MATERIALS RELATED TO THE PROPERTIES OF THE LIGHT SOURCES USED IN THE BARNS

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Abstract. The objective of this paper was determination of the reflectance coefficient of selected materials that can be used as bedding in barns for farm animals (partially dehydrated digestate from BGS and the same partially dehydrated digestate with the addition of calcium hydroxide (hydrated lime in the form of powder) in the amounts 0.25, 0.125 and 0.0625 kg per 1 kg of partially dehydrated digestate) depending on the optical properties of the light sources used in barns (mainly in particular linear fluorescent lights) and dampness of these materials. We compare the spectra of impacting and reflected light including their energy. We ascertained that with the increasing dampness of the bedding material, a small but varying shift in wavelengths of the spectrum of the reflected light towards higher values occurred for all materials. At the same time, also the value of the colour temperature of the reflected light changed. The impacting and also reflected light and their spectra were measured by the radiometer with 0.5 nm resolution. Measuring was executed in the measuring device and repeated for each selected bedding material and each light source. All results were statistically processed by non-parametrical methods due to small sets of the measured data.

Keywords: dehydrated digestate, hydrated lime, coating material, fluorescent light.

Introduction

Lighting of barn premises that serve in particular for the breeding of milk cattle was improved in the last few decades. The reason is not only the technological progress in the field of available light sources, but also new findings concerning the impact of light in particular on the life span and health of the bred animals. The impact of the intensity of lighting higher than 60 lx, which is the requirement of minimum lighting of barns for milk cattle in the Czech Republic (ČSN 36 00 88), and the length of the light day of 15-16 h provably increases the performance of cattle [1; 2]. Convenient light spectrum, for instance, influences the progress of photocatalytic processes in the wall coatings with colour with the addition of photocatalytic TiO_2 for air-cleaning [3; 4].

Lighting of barns for milk cattle is usually combined, which means that daylight is combined with artificial lighting, usually fluorescent lights. With regard to the construction solution of barns, with predominant remodelled buildings K174, K96 and other originally stanchion barns over new buildings, the sum of openings for the intake of daylight is still insufficient. Additional lighting with artificial light is therefore necessary. The indoor stable area is still divided into smaller spaces (box beds, etc.) so the light (both natural and artificial) reflections many decrease its intensity with each reflex. Reflection areas (including animal skin, bedding or excrements in the muck hall) have rough and usually darker surface (with the exception of walls and ceilings, which are usually coated with hydrated lime-based treatment). Therefore, only a fraction of the original intensity of the light arrives to the inside area where the animals live. The light from the artificial light sources is usually directed from top to bottom (which is usually caused by suspending the used fluorescent lights), and therefore its majority is absorbed by horizontal surfaces and bedding on the floor or the surface of standing or lying animals (approx. 25 % to 50 % of the original light intensity inside the barn). Since, apart from straw, dehydrated digestate from agricultural BGSs is used as bedding, it is important to know also its optical properties. BGSs are often operated right in the agricultural complexes of barns which makes the use of partially dehydrated digestate easier for both fertilizing and the above-stated purpose. Reflection of the light occurs on the top of the bedding and is easy to describe by reflectance (reflection coefficient) of the analyzed material, which is often expressed by a chart figure (for defined conditions) for the given material.

The objective of this paper is in particular to describe and quantify the selected optical properties of partially dehydrated digestate, which is more and more often used as a majority element of bedding in the milk cattle barns. Laboratory measuring was also executed for a mixture of partially dehydrated digestate and hydrated lime because hydrated lime is, among other things, known for its disinfection effects. Adding hydrated lime in partially dehydrated digestate therefore causes elimination of unwanted microorganisms (e.g., enterococci). These microorganisms may, in pure partially dehydrated digestate without adding further technological processes such as, for instance, composting in stripe bulks during which the unwanted microorganisms are eliminated thanks to natural thermic effects, occur in the bedding. Quantification of these properties is stated with regard to practical use in barns. With regard to the influence of the walls of the barn buildings on the resulting lighting intensity also reflectance of various materials used for the barn wall coatings both in horizontal and vertical direction is evaluated. In laboratory conditions, reflectance is easy to measure (taking into account the situation in the barn). During laboratory experiments, it is necessary to respect the fact that spot light source reflectance is not measured. With regard to the above-described real conditions in the barn buildings, only area light sources and their diffusion reflectance from the measured bedding was examined.

Materials and methods

Measuring of reflectance of partially dehydrated digestate and the selected coating material was executed using the BLACK-Comet spectrometer of EPP2000 type with the 200-1060 nm range, from the StellarNet producer from the USA. During measuring of reflectance of both stated materials we proceeded in the same way. As a light source, we used fluorescent lights with the "warm white" spectrum fixed horizontally in line, in the height of 2.45 m over the area of the lab. Distance of the measuring point for the material reflectance from the light source was 1.45 m. Light radiation always entered the spectrometer over integration cube. Reflectance was measured for two groups of materials.

- Partially dehydrated digestate with initial moisture of 81% and the same partially dehydrated digestate with the addition of hydrated lime in the amounts 0.25, 0.125 and 0.0625 kg per 1 kg of partially dehydrated digestate. Partially dehydrated digestate with hydrated lime was thoroughly mixed and the mixture was placed in a dish with 0.475 m diameter and 0.06 m depth. Subsequently, the mixture was exposed to lower values of air flow that correspond to the air flow in milk cattle barns (0.5 +/- 0.2 $m \cdot s^{-1}$) for at least 12 hours. The surface layer of the mixture in the dish thus showed lower moisture compared to the overall moisture in the whole sample. The reflectance was measured for this surface layer of the mixture, the mixture was subsequently homogenized and the reflectance was measured again. Thus, homogenized mixture showed higher moisture compared to the moisture of the surface layer of the mixture. The level of moisture of the bedding in the barn is also uneven, as the authors verified repeatedly (bedding in the barn not only absorbs moisture partially, but also in some places, e.g., not so much used box beds, or the front part of the box bed, decrease of moisture of the bedding in particular on its surface occurs due to the air flow in the barn). The size of the measured reflectance surface was always 0.18 m^2. The reflectance was measured for few other values of moisture (see Tab. 3.).
- A number of types of coating materials used (i.e. with potential to be used) as coating/spraying of walls and ceilings inside the barn building, namely hydrated lime-based material, Primalex, Detoxy Color, anti-mould paint, pure zinc white and unbleached stucco. For coating materials we measured also the measured reflectance linear with the direction of spreading of the light radiation from the source. This situation corresponds to the coating of vertical walls in the barn. The size of the measured reflection surface was again 0.18 m^2.

With regard to the spectrum of the used fluorescent lights that provide more energy in the area of shorter wavelengths, we also measured distribution of energy of this reflected radiation in individual ranges, each 100 nm wide. The individual ranges started at 400, 500, 600, 700, 800 and 900 nm. The measured and statistically processed values are stated in tables in the following text.

Results and discussion

The results of measuring the reflection coefficient for both groups of materials and for the described configurations of measuring including values of the other measured quantities are stated in Table 1, 2 and 3. Table 1 shows in detail the reflectance values (third column) for partially dehydrated digestate without the added hydradet lime and partially dehydrated digestate with various amounts of hydrated lime. The table shows that higher share of hydrated lime in the partially dehydrated digestate mixture leads to a higher value of the reflection coefficient. The difference in the value is not so big, however, it is statistically significant. The table also shows that the increased share of hydrated lime in the mixture does not cause such a big difference in the reflection coefficient compared to the impact of various levels of moisture. This impact of partially dehydrated digestate (mixture of partially dehydrated digestate and hydrated lime) moisture is better seen also in Table 1.

Table 1

Average reflectance of the light radiation from the surface of the partially dehydrated digestate

Sample	Amount of Hydrated Lime	Impact (I) and Reflection (R) Radiation			Data from the Chr omicity diagram			
		Light Radiation		Rate	Axis		Color	Direct of
		I	R	R/I	x	y	Temp.	Radiation
	kg	lx	lx	1	1	1	K	1
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
3	0.2500	919	375	0.40	0.315	0.267	5091	A
4	0.1250	919	360	0.39	0.311	0.262	5266	A
2	0.0000	919	342	0.37	0.308	0.309	5746	A
1	0.0625	919	303	0.33	0.302	0.248	5886	A
3	0.2500	883	337	0.38	0.313	0.264	5170	A
4	0.1250	883	315	0.36	0.309	0.257	5383	A
2	0.0000	883	298	0.34	0.306	0.252	5595	A
1	0.0625	883	289	0.33	0.301	0.247	5960	A
AA	-	-	-	-	-	-	-	-

Sample	Energy Radiation in Interval of the Spectrtun					Sample Moisture
	400 nm	500 nm	600 nm	700 nm	800 nm	
	500 nm	600 nm	700 nm	800 nm	900 nm	
	%	%	%	%	%	%
1	*10*	*11*	*12*	*13*	*14*	*15*
3	8.7	72.0	19.2	0.1	0	20.3
4	9.1	71.4	19.5	0.1	0	22.6
2	9.4	70.0	20.6	0.1	0	19.6
1	3.1	70.2	19.7	0.1	0	17.0
3	9.0	71.5	19.4	0.1	0	39.5
4	9.4	71.0	19.6	0.1	0	40.3
2	9.7	70.5	19.7	0.1	0	63.7
1	10.1	70.0	19.8	0.1	0	50.9
AA	5.6	77.3	17.0	0.1	0	-

Note: Hydrated lime was added to the digestate. The table contains the energy distribution of the radiation reflected from the sample surface in each interval of spectra (depending on the moisture of the surface layer). It represents the impact of radiation on the surface of the sample perpendicular to the direction of propagation of radiation. *A* is perpendicularly reflected radiation from the painted surface.

Here, the reflectance for homogenized mixture is lower than for the surface of the mixture in a dish, which has lower moisture as shown in column 15 of Table 1. When assessed visually, the surface layer of the mixture is of lighter colour, and therefore it reflects the impacting light more. This only confirms a generally known fact [5; 9]. Water, causing higher moisture of the mixture, is stored mostly in the intercellular space of fibrous elements of the partially dehydrated digestate, not between the particles themselves. These are, with regard to the texture of the partially dehydrated digestate, too big to keep the absorbed water in its volume [6]. Smaller share of water is bound in the mixture on the surface of the hydrated lime particles [7; 8]. The comparison of the data in columns 5 to 8 that concern the data from the chromicity diagram for light reflected from the surface of the partially dehydrated digestate (i.e. partially dehydrated digestate mixture) with light directly impacting integration cube from the source (data concerning the properties of light impacting directly from the source are stated in the last line of Table 1) is more interesting. This table also shows that there is not a significant difference between the energy of reflected and directly impacting light in division according to individual spectrum ranges (columns 10 to 15 of Table 1). This also follows that the reflected light has higher wavelength than the impacting light. The width of the used interval of 100 nm is too big for a detailed analysis of the division of energy of light inside the range. From the division of energy of the reflected light in individual ranges it is obvious that increased share of hydrated lime in the mixture is neither reflected on a different division of light energy in individual ranges.

Table 2

Average reflectance of different coating materials

Coating Material	Impact (I) and Reflection (R) Radiation			Data from the Chromicity Diagram				
	Light Radiation		Rate	Axis		Wave	Color	Direct of
	I	R	R/I	x	y	Character.	Temperature	Radiation
	lx	lx	1	1	1	nm	K	1
1,2	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Pure zinc white	476.1			0.340	0.318		4453	Down
		308.5	0.640	0.310	0.274	541.5	4985	A
		303.2	0.630	0.312	0.265	701.0	5339	B
Detoxy color (older coating)	474.3			0.340	0.308		4470	Down
		301.8	0.636	0.317	0.271	541.5	5036	A
		298.5	0.629	0.312	0.264	5 365.0	5330	B
Anti-mould paint	478.0			0.340	0.309		4471	Down
		301.1	0.629	0.316	0.269	540.5	5091	A
		299.0	0.625	0.311	0.264	701.0	5350	B
Primalex	476.0			0.340	0.318		4986	Down
		298.1	0.626	0.316	0.270	701.0	5094	A
		297.2	0.624	0.312	0.264	701.0	5332	B
Detoxy Color (fresh coating)	478.0			0.342	0.318		4472	Down
		298.1	0.626	0.315	0.269	701.1	5186	A
		307.1	0.642	0.313	0.267	701.1	5287	B
Unblanched stucco	548.0			0.341	0.311		4452	Down
		288.2	0.525	0.310	0.259	537.0	5302	A
		296.0	0.540	0.311	0.264	701.0	5359	B

Coating Material	Energy Radiation in Interval of the Spectrum					
	400 nm	**400 nm**	**400 nm**	**400 nm**	**400 nm**	**400 nm**
	500 nm	**500 nm**	**500 nm**	**500 nm**	**500 nm**	**500 nm**
	%	%	%	%	%	%
1,2	*11*	*12*	*13*	*14*	*15*	*16*
Pure zinc white	3.0	3.0	3.0	3.0	3.0	3.0
	2.7	2.7	2.7	2.7	2.7	2.7
	2.6	2.6	2.6	2.6	2.6	2.6
Detoxy color (older coating)	3.0	3.0	3.0	3.0	3.0	3.0
	2.6	2.6	2.6	2.6	2.6	2.6
	2.6	2.6	2.6	2.6	2.6	2.6
Anti-mould paint	3.0	3.0	3.0	3.0	3.0	3.0
	2.6	2.6	2.6	2.6	2.6	2.6
	2.6	2.6	2.6	2.6	2.6	2.6
Primalex	3.0	3.0	3.0	3.0	3.0	3.0
	2.6	2.6	2.6	2.6	2.6	2.6
	2.6	2.6	2.6	2.6	2.6	2.6
Detoxy Color (fresh coating)	3.0	16.0	2.8	3.0	4.9	83.7
	2.6	1.6	2.0	2.9	5.0	85.5
	2.6	1.5	2.0	2.9	5.0	85.8
Unblanched stucco	3.0	1.6	2.8	3.0	4.9	83.5
	2.6	1.5	1.9	2.9	5.0	86.3
	2.6	1.5	2.0	2.9	5.1	85.9

Note: ***Down*** is directly incident radiation on the detector in the direction of propagation of radiation (top to bottom), ***A*** is perpendicularly reflected radiation from the painted surface of wall (surface is horizontally), ***B*** is the reflected radiation from the surface with a coating (this surface is vertically and parallel to the incident radiation

Table 2 states the reflection coefficient (reflectance) for the stated coating materials. For all tested coating materials the reflection surface was the same as the surface during the measuring of reflectance of the partially dehydrated digestate in dishes. The coating of the pad with the relevant coating material was always conducted twice. Reflectance was measured on a perfectly dried-out coating, and measuring was always repeated at least five times. Differences in light reflectance from the surface of individual materials are small even in cases where the pad with the measured coating was linear with the impacting (reflected) light (orientation B). Practically all coating materials have the same properties as the surfaces of objects of various shades of grey. This again confirms general knowledge [5; 9]. Visually "whitest" material seemed to be zinc white. The surface of all materials was rough, so we always dealt with diffusion reflectance of the light on the material surface. This was also confirmed by a plaster coating (fine stucco) on the pad. The surface of the coating was very rough compared to other materials. The level of reflectance corresponds to that.

The values in Table 3 are characteristic also for other materials than partially dehydrated digestate. Only decrease of reflectance with the increasing moisture of the coating layer is different for different materials, but not substantially. One explanation of this fact is that also visually lots of biological materials get darker with higher moisture. This causes lower reflectance of light from the surface. The difference in the reflectance of partially dehydrated digestate in the moisture interval 20 to 70 % is small. These moisture values occur in the barn, where the bedding material is partially dehydrated digestate (or its mixture with hydrated lime) and therefore, higher level of moisture cannot significantly influence its reflectance. Lower values of moisture pertain to the surface of the partially dehydrated digestate, i.e. partially dehydrated digestate mixture (in the barn, most often, the surface of the bedding in the bed, in the part by the head of the milk cow or bedding in beds that are not that much used by the cows has a lower level of moisture). This surface layer of the bedding has lower moisture and lighter color. Its decreased moisture is caused in particular by the movement of air in the barn over the bedding [8].

Table 3

Reflectance of partially dehydrated digestate (without additions) depending on its moisture content. Light rays incident normally on the surface of the digestate

Moisture of partially dehydrated digestate, %	45.0	11.4	19.6	35.1	61.3	77.0
First Measurement, 1	0.48	0.38	0.35	0.30	0.23	0.22
Second Measurement, 1	0.43	0.35	0.30	0.32	0.24	0.20
Thirth Measurement, 1	0.46	0.34	0.37	0.28	0.22	0.21
Average Value of Reflectance, 1	0.46	0.37	0.34	0.30	0.23	0.21

Conclusions

Based on the measured data and ascertained facts, we can observe the following.

1. Reflectance of light from the surface of the partially dehydrated digestate (or its mixture with hydrated lime) depends on its moisture and on the amount of hydrated lime in the mixture.
2. Reflectance of the mixture of partially dehydrated digestate and hydrated lime is always higher than the reflectance of partially dehydrated digestate without additives.
3. Reflectance of the light from the surface of the partially dehydrated digestate or its mixture with hydrated lime decreases with increasing moisture.
4. The difference in the reflectance of partially dehydrated digestate or of its mixture with hydrated lime depending on humidity is not too significant with regard to the design of lighting of barn premises and its light efficacy.

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