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CARBON DIOXIDE EMISSIONS FROM FLY-ASH IN THE RECLAMATION PROCESS

EMISJA DITLENKU WĘGLA Z POPIOŁÓW LOTNYCH W PROCESIE REKULTYWACJI

Abstract: The objective of this study was to determine the amount of carbon dioxide emitted from fly-ash reclaimed by sewage sludge and municipal waste compost, measured at a temperature of 10, 20 and 30 ^{o}C and a substrate moisture content of 60 % of maximum water capacity. Samples of ash and sludge substrates and ash and compost substrates were collected at the end of the growing season. The following mixtures were used in the study: ash with a 25 % and 50 % sludge or compost addition. Carbon dioxide emission was determined by the absorption method with the use of 0.05 mol NaOH · dm^{-3}. Substrate samples were put in 1 litre jars and placed in a controlled environment chamber (Microclima 1000, Snijder Scientific B.V.). Samples were incubated for 72 hours. The obtained results were verified by the ANOVA analysis of variance (F test) for multi-factorial designs.

The results of the study indicate that compost and sewage sludge increase the respiratory activity of fly-ash. The rate of carbon dioxide evolution was affected by incubation temperature – a more than a 300 % increase in CO_2 emission was reported when incubation temperature was raised from 10 ^{o}C to 30 ^{o}C.

Keywords: carbon dioxide, emission, fly-ash, reclamation

Fly-ash from the process of coal combustion for energy production constitutes highly noxious waste. In Poland, this type of waste is neutralised mostly by disposal in repositories. Fly-ash can be utilised in road and industrial construction, in the production of construction and ceramic materials, it is also deployed to stabilise soils, to fill excavation pits, reclaim degraded areas and treat municipal waste [1–4]. Combustion waste deposited at landfill sites is a source of dust pollution and it requires reclamation. One of the methods of reclaiming energy waste sites involves the introduction of organic substances followed by sodding [5].

Carbon dioxide emissions are determined, among others, by the rate of fossil fuel exploitation, biomass combustion and industrial activity. Deforestation is a major

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contributor to higher CO_2 emissions. Carbon dioxide is also formed during the respiratory activity of various organisms, and it is absorbed by plants in the process of photosynthesis. The rate of CO_2 formation in soil is affected by the following factors: temperature, moisture content, pH level of soil and the type of soil use [6, 7].

The intensity of carbon dioxide emissions may be an indicator of biological processes taking place in the soil. This study attempts to determine the amount of carbon dioxide emitted by fly-ash from coal combustion, reclaimed with the use of sewage sludge and compost. The study was carried out under controlled temperature and humidity conditions on the assumption that temperature and moisture content are the main determinants of CO_2 emission.

Materials and methods

The study was performed with the use of material from a 6-year pot experiment which aimed to determine the influence of sewage sludge and compost on fly-ash reclamation. Fly-ash was mixed with sewage sludge and compost at different proportions. The experimental treatments are presented in Table 1. The experiment was carried out in three replicates.

Respiratory activity, measured in terms of carbon dioxide emission, was investigated in the sixth year of the experiment at the end of the growing season.

Fly-ash used in the experiment was obtained from the Municipal Heating Plant (MPEC) in Olsztyn. In line with soil classification standards, the investigated ash was classified as sandy silt. In the first year of the experiment, the carbon content of ash was determined at 12.86 % at a pH level of 8.8. The compost used in the experiment consisted of stabilised sewage sludge, leaves, grass, sawdust and organic wastes. The carbon content of compost was 5.3 % with pH of 7.7 in 1 mol KCl $\cdot$ dm^{-3}. Sewage sludge with a muddy consistency was obtained from the sludge-drying beds of the Municipal Waste Treatment Plant in Olsztyn. Sludge was abundant in nutrients: its organic carbon content reached 7.48 % with water pH of 7.9. Fresh sewage sludge with a 54.32 % dry matter content was used in the experiment.

Carbon dioxide emissions were determined by the absorption method with the use of 0.05 mol NaOH $\cdot$ dm^{-3}. Pot samples were brought to a moisture content of 50 % of maximum water capacity. They were placed in a controlled environment chamber (Microclima 1000, Snijder Scientific B.V.) in tight, 1 litre jars. Carbon dioxide emission was measured at three temperature settings: 10, 20 and 30 ^{o}C. The amount of emitted carbon dioxide was determined as described by Isermeyer [8]. The analysed substrates were brought to the desired moisture content and incubated in a phytotron chamber at the set temperature for 72 hours. Carbon dioxide emissions were measured every 24 hours, when the jars were aired and filled with fresh NaOH solutions. The applied methodology has been described in detail by Rogalski and Bes [9].

The obtained results were verified by the ANOVA analysis of variance (F test) for multi-factorial designs. Two experimental factors were adopted: dose of sewage sludge or compost and incubation temperature. Significant differences were determined by the Newman-Keuls test at a significance level of $p = 0.01$. The results of post-hoc tests are presented as homogenous groups and are denoted by respective letters in the results tables. The relationships between the tested parameters were determined with the use of Pearson linear correlation between two variables. The significance of correlation coefficients *r* was estimated at a significance level of $p < 0.01$. Statistical analyses were performed with the use of STATISTICA 8.0 PL software (StatSoft Inc. 2007).

The term *substrate* used in this study refers to both fly-ash as well as mixtures of fly-ash with sewage sludge and compost.

Results and discussion

The results of the study indicate that both the sludge and compost dose and the incubation temperature had a statistically significant impact on carbon dioxide emissions. The interactions between the investigated factors also significantly influenced the analysed parameter.

The mean emission values for all experimental treatments are presented in Table 1.

Table 1

Carbon dioxide emission [$mg \cdot kg^{-1}$ d.m. substrate $\cdot d^{-1}$] on individual experimental treatments

Treatment	Temperature [°C]			Mean for treatment
	10	20	30	
Fly-ash	38.62 a	91.45 cde	111.13 de	80.40 A
Sewage sludge	83.82 bcde	72.80 bc	156.94 f	104.52 B
Compost	24.25 a	241.54 h	204.90 g	156.90 D
Fly-ash + sewage sludge (75 % + 25 %)	93.62 cde	113.26 e	208.87 g	138.58 C
Fly-ash + sewage sludge (50 % + 50 %)	50.23 ab	102.03 cde	108.79 cde	87.02 AB
Fly-ash + compost (75 % + 25 %)	76.11 bcde	208.91 g	368.43 i	217.82 E
Fly-ash + kompost (50 % + 50 %)	37.74 a	73.97 bcd	181.62 fg	97.78 AB
Mean for temperature	57.77 x	129.14 y	191.53 z	

Values denoted by different letters are significantly different at $p = 0.01$; values are denoted by letters: a, b, ... for a comparison of dependencies between substrate type and temperature; A, B, ... for a comparison of substrate types; x, y, z – to determine the impact of temperature on carbon dioxide emission; these values belong to different homogenous groups (based on post-hoc tests).

Impact of sludge and compost dose on CO_2 emission

The addition of sewage sludge and compost to fly-ash resulted in higher CO_2 emissions from the analysed substrates in comparison with the control treatment which comprised fly-ash only. The noted differences between CO_2 emissions from substrates with a 25 % and 50 % sludge or compost content were statistically significant.

CO_2 emission was higher in treatments where fly-ash was mixed with 25 % sludge – the share of those emissions for all temperature settings increased by 72 % on average. In treatments with a 50 % sludge content, CO_2 emissions rose only by 8 % (in comparison with control). Similar dependencies were reported in treatments with a fly-ash and compost mixture – the addition of compost in the amount of 25 % and 50 % increased CO_2 emissions by 170 % and 22 %, respectively. The studies carried out by Nosalewicz [7], Quemada and Menacho [10], Gostkowska et al [11], Wong and Lai [12] to determine the amount of CO_2 emitted from different substrates fertilised with mineral and organic substances show that the addition of fertilisers increased CO_2 emissions. The above trend is supported by the results of this experiment. It should be noted, however, that a 25 % compost or sludge addition led to a much higher increase in CO_2 emissions than a 50 % dose. In a study investigating CO_2 emissions from soils transformed as a result of gravel excavation, Rogalski et al [13] observed that fly-ash mixtures with a 50 % sludge content increased carbon dioxide emissions by 39 %. CO_2 emissions from treatments supplied with 25 % sludge rose by only 13 %. A similar dependency to that noted in this study was reported by Rogalski and Bes [9] in their analysis of fly-ash and sludge substrates in the second year of the experiment conducted before the growing season.

Impact of temperature on CO_2 emissions

A statistical analysis pointed to significant differences in CO_2 emissions for every temperature range. In view of the mean levels of CO_2 emission reported in all experimental treatments, when the samples were incubated at 10 ^oC, carbon dioxide emissions reached 57.77 $mg \cdot kg^{-1} \cdot d^{-1}$. A 10 ^oC rise in incubation temperature (from 10 ^oC to 20 ^oC) increased CO_2 emissions by 123 %. When the temperature was increased by another 10 ^oC (from 20 ^oC to 30 ^oC), emissions rose by 48 %. The greatest change in the amount of emitted CO_2 was noted when incubation temperature was increased from 10 ^oC to 20 ^oC. As regards the fly-ash and compost mixture (75 % + + 25 %), a 10 ^oC increase in incubation temperature raised carbon dioxide emissions by 175 % (from 76.11 to 208.91 $mg \cdot kg^{-1} \cdot d^{-1}$). In the remaining treatments, CO_2 emissions increased from 21 % to 137 %. When incubation temperature was raised by another 10 ^oC, the emission levels of the analysed gas increased by 7 % to 146 %. Carbon dioxide emissions increased by 231.5 % on average when incubation temperature rose by 20 ^oC (from 10 ^oC to 30 ^oC). In a study conducted by Rogalski et al [13], the respiratory activity of light soil fertilised with sewage sludge increased proportionally to the rise in incubation temperature. Carbon dioxide emissions from substrates incubated at 30 ^oC were 466 % higher than from the same substrates incubated at 10 ^oC. The optimal incubation temperature for the substrates analysed in this study was 20 ^oC and it is consistent with the findings of, among others, Wlodarczyk et al [14] and O'Connel [15].

The analysis of Pearson linear correlation between two variables showed that carbon dioxide emissions were not correlated with the applied compost or sludge dose. Statistically significant correlations were observed between incubation temperature and CO_2 emissions at $r = 0.72$ ($p < 0.01$, $n = 27$) for fly-ash and sludge substrates, and at $r = 0.69$ ($p < 0.01$, $n = 27$) for fly-ash and compost substrates.

Conclusions

1. The results of this experiment suggest that the addition of fly-ash to sewage sludge and municipal waste compost contributes to an increase in CO_2 emissions. Carbon dioxide emissions from fly-ash and compost substrates were on average by 40 % higher than from fly-ash and sludge mixtures.

2. The addition of sewage sludge or compost to fly-ash led to statistically significant differences in the amount of emitted CO_2. The obtained results indicate that a content of organic substances in substrates increased CO_2 emissions by 68 % on average.

3. The amount of emitted CO_2 was significantly affected by incubation temperature. A temperature rise of 10 ^{o}C increased emission levels by 86 % on average in all treatments. The optimal temperature for the analysed substrates was 20 ^{o}C.

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EMISJA DITLENKU WĘGLA Z POPIOŁÓW LOTNYCH W PROCESIE REKULTYWACJI

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Abstrakt: Celem pracy było określenie ilości wydzielonego ditlenku węgla z popiołu lotnego rekultywowanego osadem ściekowym oraz kompostem z odpadów komunalnych, w ustalonych temperaturach: 10, 20 i 30 ^{o}C, przy wilgotności podłoży równej 60 % maksymalnej pojemności wodnej. Próbki podłoży popiołowo-osadowych i popiołowo-kompostowych pobrano po zakończeniu okresu wegetacji. W doświadczeniu wykorzystano następujące mieszaniny: popiół z 25 % i 50 % dodatkiem osadu lub kompostu. Pomiar emisji ditlenku węgla prowadzono metodą absorpcyjną z 0,05 mol NaOH · dm^{-3}. Słoje o pojemności 1 litra, z próbkami odpowiednich podłoży, umieszczano w komorze klimatyzacyjnej Microclima 1000 (Snijder Scientific B.V.). Próbki inkubowano przez 3 doby. Wyniki uzyskane z badań poddano analizie wariancji ANOVA (test F) dla układów wieloczynnikowych.

Przeprowadzone badania wykazały, że dodatek kompostu lub osadu ściekowego powoduje zwiększenie aktywności respiracyjnej popiołu lotnego. Intensywność wydzielania ditlenku węgla zależała od temperatury inkubacji i przy jej wzroście z 10 ^{o}C do 30 ^{o}C emisja CO_2 zwiększyła się o ponad 300 %.

Słowa kluczowe: ditlenek węgla, emisja, popiół lotny, rekultywacja