# Environmental effects of the burning of the straw for energy purposes

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**Abstract:** Long-term using of fossil fuels has caused global climatic changes. Using of the renewable energy sources based on the field crop biomass can be considered as a tool allowing compensating the negative consequences of the fossil fuels. Among different types of biomass based fuels the straw baled in the form of square bales plays an important role. Until now the research pays only small attention to the environmental effects related to the using of the straw for energy purposes.

The aim of the paper was to analyze the effect of moisture content of the straw used for energy purposes. The straw has been baled to the form of large square bales. The straw bales were burned in special boiler. The quality of incineration process was monitored for different straw moisture content and also from the point of amount of CO2, CO, NO2, NO emissions which were released during the incineration process.

Based on the experimental results, we can confirm that the increased straw moisture content (15.9%) there were obtained lower values of concentrations of emissions, but the process of burning was significantly slower. There was a longer burning of the same amount of the straw material. It means that the total amount of emissions released from the combustion of material with higher moisture content is equal to the emissions produced during combustion of dry straw. In conclusion it can be stated that the handling of straw bales and the method of bales storage affect straw moisture content, which then affects the quality of combustion in terms of the amount of energy gained.

**Keywords:** baled straw for energy purposes, laboratory experiments, straw burning, emission factors

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## 1 Introduction

In the context of EU energy policy biomass used for energy purposes has become very important commodity. Agricultural land, where the main crops are grown is considered as the most important source of biomass (Maga et al., 2008). Biomass as a secondary raw material mostly comes from agricultural land in the form of straw as by product from cereals cropping systems, as a hay or also as a cuttings from cut of fruit trees and vine grapes. Biomass can also be a major product in the case of energy crops grown on arable land. A great source of biomass suitable for energy purposes are forests. From the energy point of view the agricultural biomass can be used to produce heat for space heating and water heating (Hussein et al., 2012).

As mentioned by Barkoczi et al. (2012) claimed, the using of biomass as renewable energy source brings the following advantages:

- biomass is permanently produced yearly in the given area,
- using of biomass for energy purposes has positive effect on the economic growth of the rural areas,
- biomass can be considered as stable renewable energy source as its amount, energy potential and market price can be determined for longer period,
- production of energy from biomass is neutral in relation to the creation of greenhouse gases,

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- growing of crops for energy purposes has a positive effect on the protection of soil and water regime in the soil.

In connection with using of straw for energy purposes the attention of the research is very often focused on the environmental impacts of this kind of renewable energy sources. During straw burning processes in order to obtain heat, there are produced emissions. The amount and sort of these emissions are subject of the permanent investigation. As the main types of emissions resulting from the combustion of straw can be considered: carbon monoxide CO, nitrogen oxides N2O, NO and NO2. Several sources indicate that the combustion is carbon neutral because the amount of carbon dioxide produced is comparable to the quantity consumed by plants during their growth (photosynthesis). It is a simplified view because the trees grow for years and the wood is burned immediately. Combustion of the biomass causes dangerous substances, but they can be affected by the technology of combustion processes (Nikolaisen et al. 1998).

In connection to the above mentioned problems related to the use of straw for energy purposes the main aim of the presented paper it was to analyze the effect of moisture content of the straw used for energy purposes.

## 2 Material a methods

The aim of the paper is to analyze the amount of emissions produced as a result of burning of the straw for energy purposes in relation to the straw storage conditions and straw moisture content. According to the used methodology there was used wheat straw baled by straw large square baler KRONE Big Pack 1290XC trailed on the field by tractor JOHN DEERE 7200R and JCB FasTrack 3200 (Figure1).

A B

Figure 1 A - straw large square baler KRONE Big Pack 1290XC trailed on the field by tractor JOHN DEERE 7200R, B - straw large square baler KRONE Big Pack 1290XC trailed on the field by tractor JCB Fast Track 3200

For the research purposes there was formulated the scientific hypothesis:

“Handling of the straw bales and their storage in storage facilities have an effect on the straw moisture content as well as on the amount of emissions released during burning process from the boiler.“

From the field the straw bales were transported to the laboratory storage facilities. During storage the straw moisture content was continuously measured by two methods:

1$^{st}$ method was done by moisture content meter AGRI COMPUTER CZ 931(Figure 2) in the bale depth of 200 mm and 400 mm. The apparatus is programmed in order to determine the moisture content of the 15 different kinds of grain and seeds. The calibration of the moisture meter is changing according to changes of the surrounding air temperature and grain temperature. The apparatus is equipped by the probe which allows to determine the straw bale moisture content after inserting the probe into the bale within the moisture content range from 12% to 35%. If the moisture content is bellow12%, the display of the apparatus shows the symbol "LO", what means the lowest measured moisture content is 12%. The same principle is used in case of the highest measured moisture content, which is 35%. In case of higher moisture content on the display there can be seen the symbol "HI".


Figure 2 Straw moisture content meter AGRI COMPUTER CZ 931

2nd method was: gravimetric method when straw samples were taken from the bales. It is the most accurate method of the determining the straw moisture content based on standard EN 14774-1 "Solid biofuels Determination of moisture content. Oven dry method. Part 1: &Total moisture. Reference method".

The moisture content measured by above method is based on the mathematical Equation 1:

$$M_{ar} = \frac{M_2 - M_3}{M_2 - M_1} * 100,\ \% \qquad (1)$$

where:

$M_{ar}$ - moisture content, %

$M_1$ - weight of the empty dish, g

$M_2$ - weight of the full dish before draying, g

$M_3$ - weight of the full dish after draying, g

By using of above method we have determined the straw moisture content, which was purposefully moisturized in order to know the effects of straw moisture content changes on the amount on emissions during the straws burning in laboratory conditions. For the measuring of the weight of dishes and straw samples there were used Sartorius Basic scales (precision ±0.001 g). The straw was dried in "HS 61 A" drier, which was equipped with the metal plates and dishes used for straw samples drying.

The samples of the straw taken from bales were burnt in special hot water boiler KTP 256 m (ROJEK manufacturer) with nominal output 25 kW (Figure 3). Used boiler has a modern construction and effective pyrolytic process with common burning out which enables to burn different types of biomass (such as dry solid biomass, damp wooden chips and fresh sawdust). This hot water boiler is made of metal plates and is completely isolated by thermal insulation. It is a new type of energetic boiler having a patented design of the incineration chamber. It is design allow to use the heat developed by fuel burning. The grate cooled by the water is part of a boiler attachment.

Figure 3 Hot water boiler KTP 256 m (ROJEK manufacturer)

Incineration chamber is equipped by large-size fire feeding doors allowing easy handling with the material during placing the material into the chamber. Regulation of the air flow allows to obtain a long time of burning between each moment of fire feeding. On a front side of a boiler there is located pressure indicator and thermometer. The power is regulated manually or by the air input flow regulator. On a pipe of chimney at the outlet of boiler exhaust gases there are three measuring places to measure amount of emissions in exhaust gases.

The boiler was directly connected with the portable emission analyzer TESTO 350 XL (Figure 4) having a sampling probe with the 500 mm length. During straw burning the emission analyzer has allowed to measure the following gases: CO, CO2, NO and NO2. The data were subsequently statistically analyzed and evaluated.

A B

Figure 4 A - Emissions analyzer TESTO 350 XL connected to the computer, B - Sampling probe emission of analyzer connected to the smoke flue

## 3 Results

As it was above mentioned the wheat straw was incinerated in a boiler KTP 25m (ROJEK manufacturer). For the purpose of the automatic recording of the obtained data we have used a computer which was connected with the portable emission analyzer TESTO 350 XL. In order to make a fire in a boiler we have used the wood and paper. In order to start the measuring of amount of emissions the boiler should to reach the temperature 60 ℃. On a pipe of chimney at the outlet of boiler exhaust gases there were placed three exhaust gases measuring points and portable emission analyzer was connected. After making a fire in the boiler and complete burning of a wood we have started gradually to insert the straw with moisture content of 12%, and it was burnt approximately for 37 min. The temperature of the exhaust gases during burning was approximately 296 ℃. After this stage we have started to burn the straw having moisture content of 15.9%. During burning it was necessary to rake up the straw as its higher moisture content has caused the choking and fuming of the fire place. It affected the process of emissions measuring. Due to the permanent opening of the boiler doors the large amount of the air has come to the area of the fire place. The process of the moisturized straw burning lasted for 42 min and the temperature of the exhaust gases temperature decreased compared with dry straw to an average of 156 ℃. Uneven metering (dosing) of the straw during its combustion caused a situation where emission analyzer due to the low emission values was not able to measure the values of emissions. The entire combustion process was influenced by the dose of material and its discontinuity.

The portable emission analyzer TESTO 350 XL is calibrated for accurate measuring of emissions. The evaluation of the data obtained has been based on emissions limits, which are defined in the Collection of Laws No. 706/2002. During our experiments we have measured and evaluated the values of CO, CO2, NO a NO2 emissions. The results of experimental measuring are presented in Tab. 36 a 37, where are shown the basic statistic parameters of selected data obtained during experiments. The sum of the measured data shows the diversity of the monitored files. The first statistic set there were recorded 1485 data and the second set there it was 2110 data. The values of CO, NO and NO2 emissions are expressed in internationally recognized units of ppm (parts per million). (See Table 1 and Table 2)

**Table 1 Descriptive statistics of a data characterizing the effect of straw moisture content 12% on the amount of emissions during straw burning**

| Statistic parameter | Emission factors | | | |
|---|---|---|---|---|
| | **CO, ppm** | **$CO_2$, %** | **NO, ppm** | **$NO_2$, ppm** |
| Mean value | 3713.17 | 4.69 | 85.68 | 0.03 |
| Standard deviation | 1498.03 | 3.91 | 68.72 | 0.16 |
| Sharpness | 1.08 | 1.97 | 0.04 | 74.52 |
| Obliqueness | 0.54 | 1.56 | 1.02 | 8.05 |
| Range | 8709 | 18.21 | 323 | 1.8 |
| Minimum | 556 | 1.01 | 9 | 0 |
| Maximum | 9265 | 19.22 | 332 | 1.8 |
| Summary | 5491783 | 6946.5 | 126723 | 38.4 |
| Number of dates | 1479 | 1479 | 1479 | 1479 |

**Table 2 Descriptive statistics of a data characterizing the effect of straw moisture content 15.9 % on the amount of emissions during straw burning**

| | Emission factors | | | |
|---|---|---|---|---|
| **Statistic parameter** | **CO, ppm** | **$CO_2$, %** | **NO, ppm** | **$NO_2$, ppm** |
| Mean value | 3548.15 | 2.65 | 61.29 | 0.0 |
| Standard deviation | 2000.09 | 2.79 | 62.01 | 0.0 |
| Sharpness | -0.35 | 5.55 | 6.08 | 0.0 |
| Obliqueness | 0.74 | 2.43 | 2.49 | 0.0 |
| Range | 8524 | 16.38 | 345 | 0.0 |
| Minimum | 915 | 0.7 | 13 | 0.0 |
| Maximum | 9439 | 17.08 | 358 | 0.0 |
| Summary | 7486590 | 5598.27 | 129320 | 0.0 |
| Number of dates | 2110 | 2110 | 2110 | 2110 |

### 3.1 Evaluation of the $CO_2$ emissions

Based on the data obtained, it can be stated that values of carbon monoxide CO emissions detected in exhaust gases of straw having a 12% moisture content have reached 3713.17 ppm (maximum 9265 ppm and minimum 556 ppm. Values of carbon monoxide CO emissions detected in exhaust gases of straw having a 15.9% moisture content have reached 3548.15 ppm (maximum 9439 ppm and minimum 915 ppm. If we compare values of carbon monoxide CO emissions detected in both cases we can see the differences in mean value, and maximal and minimal values. The mean value (the average), we have used to determine the value, which is close to the reference values of CO exhaust gas emissions contained in the file. Downward trend was observed in the second case, in case of straw with a moisture content of 15.9% which decreased by 165.02 ppm. The maximum and minimum values of these statistical parameters were increasing, and for the straw with moisture content of 15.9% the minimum value was increased of 359 ppm and a maximum of 174 ppm.

From the graph (Figure 5) it can be seen the unevenness of the straw burning. From the curves we can see the occurrence of extremely low and extremely high levels of carbon dioxide emissions. Just extremely high readings were recorded due to intermittent straw dosing and its incomplete combustion. Since dosing material was not provided by any metering device, but it was dosed sequentially, this affected the measured emission values. The emission analyzer has recorded this unevenness. We suppose that due to these reasons there was observed the largest air pollution by CO emissions.

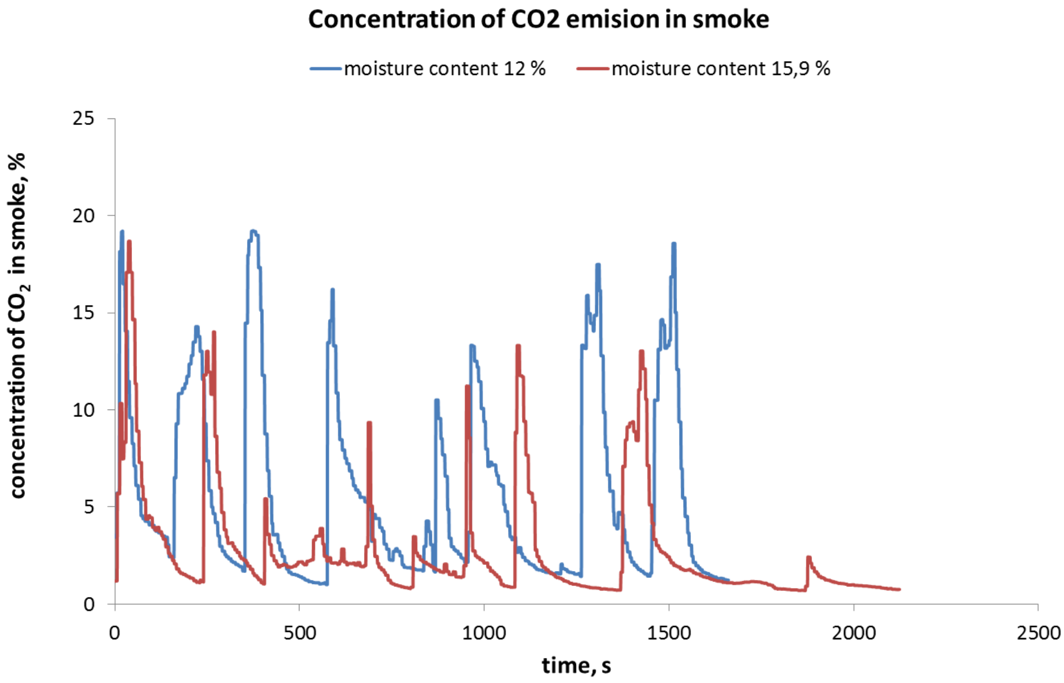


Figure 5 Comparison of the course of the $CO_2$ emissions in exhaust gases in case of burning of wheat straw having a different moisture content

### 3.2 Evaluation of the NO emissions

Mean value of the content of emissions of the nitric oxide NO found in exhaust gases of straw with moisture content 12% were on average 85.68 ppm when maximum value was 332 ppm a minimum value was 9 ppm. Temperature of the exhaust gases was 296 ℃. When the straw moisture content was increased at the level 15.9%, the mean value of the content of emissions of the nitric oxide NO found in exhaust gases were on average 61.29 ppm, when maximum value was 358 ppm a minimum value was 13 ppm and temperature of the exhaust gases was 156 ℃. Increasing of the straw moisture content by 3.9% has caused the decrease of the mean value of the content of emissions of the nitric oxide NO found in exhaust gases by 24.4 ppm. The temperature of the exhaust gases was decreased by 140 ℃. Decreasing of the mean value of the content of emissions of the nitric oxide NO in exhaust gases related to burning of straw with higher moisture content was caused by decrease of burning temperature. Based on results obtained it is possible to state that creation of the NO emissions during straw burning is significantly affected by incineration temperature. Results obtained fully comply with emission limits defined in the Collection of Laws No. 706/2002. (See Figure 6)

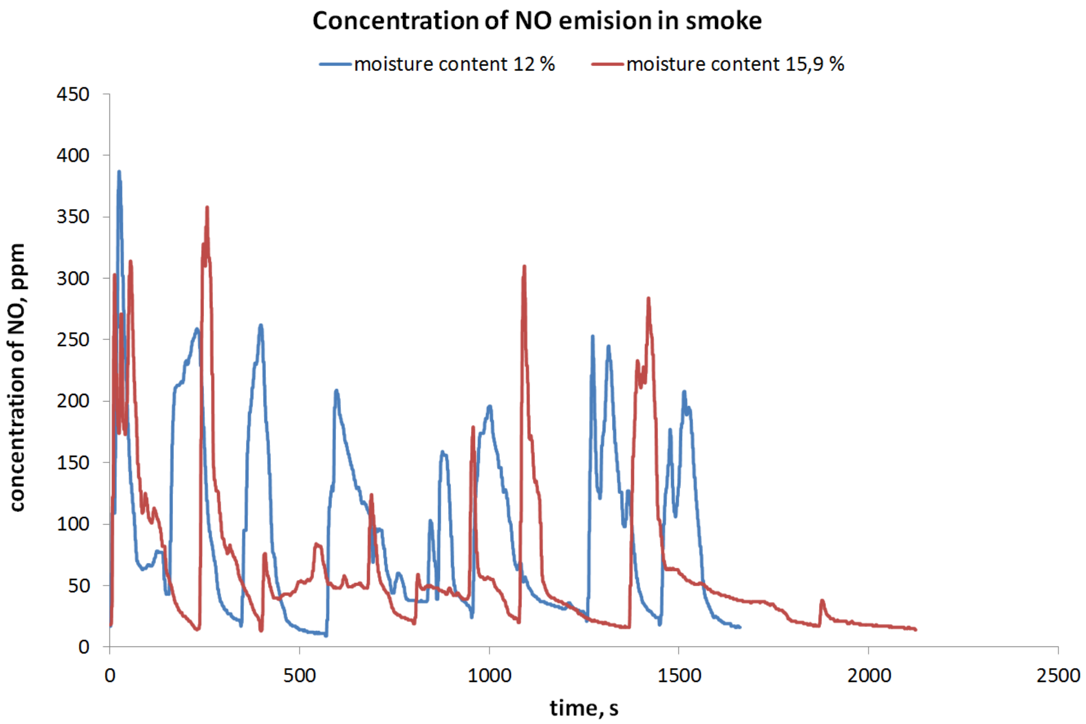


Figure 6 Comparison of the course of the nitric oxide NO emissions in exhaust gases in case of burning of wheat straw having different moisture content.

### 3.3 Evaluation of the $NO_2$ emissions

Emissions of the nitrogen dioxide NO2 was measured only in case of the burning of straw with 12% moisture content. When there was burnt the straw with 15.9% moisture content, the values of emissions of the nitrogen dioxide NO2 was below 0.1 ppm and the sensor of the emission analyzer was not able to record them. Therefore we could evaluate statistic data characterizing the emissions of the nitrogen dioxide NO2 related to the burning of the straw with 12% moisture content. Mean value was relatively low – only 0.03 ppm, when maximum value was 1.8 ppm a minimum value was 0.0 ppm. Standard deviation in this case was 0.16 ppm. The indicator of the statistical symmetry of the experimental data (namely, sharpness and obliqueness) was high when compared with above mentioned gases. They characterized the concentration of the other values in the file. In this case, both indicators were positive.

## 4 Conclusions

Based on the analysis of the burning of wheat straw with moisture content of 12% and 15.9%, we can conclude that the operation of straw burning in ROJEK boiler (rated output of 25 kW) has been largely influenced by the discontinuity of material metering and moisture content of the burned straw. When burning the straw with the moisture content of 12% there was sufficiently used energy potential of the straw. This led to the increase of the exhaust gas temperature at the level of 296 ℃. Conversely, when there was used straw with moisture content moisture of 15.9%, the exhaust gas temperature decreased to a value of 156 ℃. This decrease can be explained by the fact that part of the energy produced by straw burning was used to evaporate the water contained in straw. The energy potential of the straw as biofuel was not sufficiently used. Based on results obtained it can be stated that amount of the NOx emissions is first of all affected by the temperature of the burning process. Therefore it is very important to secure the continual metering of the straw during burning process, as well as using of the straw with moisture content around 12%.

In case of straw moisture content 12%, the following average values of the emission factors were recorded –

CO: 3713.17 ppm, CO2: 4.69%, NO: 85.68 ppm, and NO2: 0.03 ppm.

In case of straw moisture content 15.9%, the following average values of the emission factors were recorded – CO: 3548.15 ppm, CO2: 2.65%, NO: 61.29 ppm, and NO2: NA (not available).

Based on the experimental results, we can confirm that the increased straw moisture content (15.9%) there were obtained lower values of concentrations of emissions, but the process of burning was significantly slower. There was a longer burning of the same amount of the straw material. It means that the total amount of emissions released from the combustion of material with higher moisture content is equal to the emissions produced during combustion of dry straw. In conclusion it can be stated that the handling of straw bales and the method of bales storage affect straw moisture content, which then affects the quality of combustion in terms of the amount of energy gained.

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