Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 95 (2016) 208 – 215

Energy Procedia

International Scientific Conference "Environmental and Climate Technologies", CONECT 2015, 14-16 October 2015, Riga, Latvia

# Charcoal production in a continuous operation retort. Experimental data processing

Krista Klavina*, Janis Klavins, Ivars Veidenbergs, Dagnija Blumberga

*Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV–1048, Latvia*

**Abstract**

The charcoal industry has recently regained the spotlight along with other renewable resources, not from its previous ill repute as a cause of deforestation but as one of the tools for climate change mitigation. In this paper a study with an experimental evaluation of a charcoal production technology is carried out in an industrial facility. The investigated technology is a state-of-the-art continuous operation automated retort which is comprised of a monitoring system continuously registering process characteristic temperatures. The raw material, biomass, passes through three different stages in the retort - biomass heating and drying, biomass carbonization, and charcoal cooling. These process sections are described and analyzed according to the relevant temperatures. The obtained data is processed using Statgraphics Centurion Statistical data analysis tool. This study draws attention to the importance of a scientific approach to charcoal production with optimized process parameters directing the charcoal industry towards the increase of production sustainability.



Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment.

*Keywords:* pyrolysis; temperature; biochar; free fall reactor; statistical analysis

## 1. Introduction

The traditional charcoal markets include the metallurgical industry, activated coal in medical use, filtrating and purification applications, as a barbecue fuel, and, in developing countries, as a household fuel [1]. Further on, through a pyrolysis process biochar can be obtained. Biochar is defined as char that can be used as a soil

* Corresponding author. Tel.: + 371 67089943
*E-mail address*: krista.klavina@rtu.lv


Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment.
doi:10.1016/j.egypro.2016.09.051

amendment, thus enhancing soil fertility, as well as trapping atmospheric carbon in the ground [2]. This shows the versatile application of this renewable material, and also the possibility to substitute a share of fossil material use in energy and material industries, as well as mitigate climate change. A comprehensive overview of the pyrolysis process, different feedstock, technologies, including economic aspects is discussed in a paper by Jahirul et al. [3].

Batch-type kilns are the technology that was developed centuries ago to produce one of the first charcoal fuels. The production method with different variations has mostly been used up until the present. The introduction of pyrolysis gas recirculation in the pyrolysis chamber, thus supplying the heat that is necessary for the pyrolysis process without using a part of the input material for this purpose, and lowering the pyrolysis gas emissions into the atmosphere is one of the most important updates of the technology. The next step that has been taken is transitioning from batch-type production to continuous production. Continuous charcoal production retorts are a comparatively new technology. Continuous retorts have enhanced productivity by taking up the same space, but using it continuously for charcoal production. In the batch-type kilns the input material is in turn heated and carbonized, and then the charcoal is left to cool for some time. In the continuous retorts the input material is inserted from above and falls out from the bottom into the cooling chamber, and is automatically conveyed to package and storage locations. The process is highly automated, thus significantly increasing the possibility for process control.

Charcoal production in a continuous production retort with the Lambiotte carbonization system is studied in this paper. The temperature monitoring data is obtained and analyzed to describe the internal processes of the retort. The results can be used in process mathematical modelling, and in calculations for the energy balance estimation.

**Nomenclature**

| | |
|---|---|
| T1 | effluent pyrolysis gas temperature, °C |
| T2 | gas temperature before the drying zone, °C |
| T3 | hot pyrolysis gas temperature, °C |
| T4 | temperature of the cooled pyrolysis gas, °C |
| T5 | air supply temperature, °C |
| T6 | temperature in the carbonization zone upper layer, °C |
| T7 | temperature in the carbonization zone bottom layer, °C |

## 2. Methodology

### *2.1. Industrial experiment*

The industrial experiment takes place during the process of the facility's environmental performance evaluation. The environmental performance results are discussed in the study by Kļaviņa [4]. The experiment takes place at a real-life industrial charcoal production retort with the process of continuous carbonization of cellulosic materials initially patented by Auguste Lambiotte in 1942 [5].

The permit for polluting activities needed for the duration of the experiment is arranged beforehand. The period of experimentation is 23 days. Charcoal is produced from a mix of birch and alder firewood. During the course of the experiment, the initial stage consisted of the preparation of the input material – cleaving of wood logs, and drying the first input portions. The retort was started and worked around-the-clock, the only exception being for servicing. Likewise, the input material drying was continued throughout the experiment. The technology requires regular feed material, and a symmetrical material distribution in the retort for the best results. It is essential to ensure that the input material moisture content does not exceed 25 %.

A schematic representation of the retort is illustrated in Fig. 1. The scheme describes the retort by dividing it into three zones in the charcoal production process – drying zone, carbonization zone, and the cooling zone. These three zones are indeterminate, as the input material is inserted from the top with a skip conveyor, and moves from one zone to the next by free gravitational pull. The retort is 16.3 m high, with the volume of 600 m$^3$, and has the estimated production of 2,000 tons of charcoal per year [6].

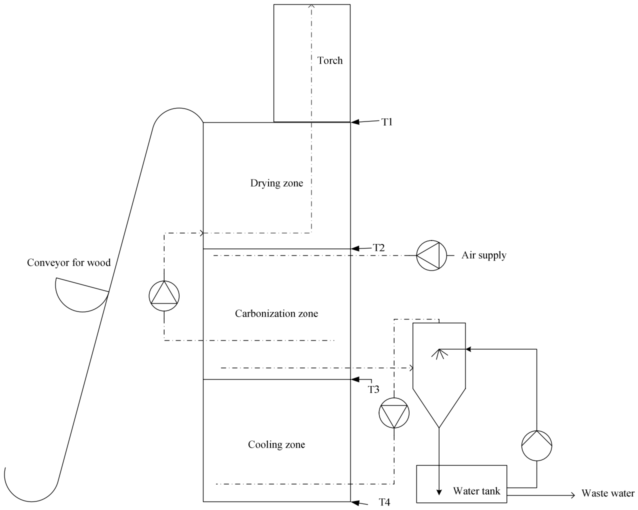



Fig. 1. Schematics of the industrial charcoal production retort.

The locations of the temperature measurements that are registered in the plant control panel are indicated in Fig.1 with the capital letter T. Temperature measurements are registered at each thermocouple location all throughout the experiment with a one minute time step. The collected data is retrieved after the experiment time period, when the retort is shut down. Parallel to the temperature measurements, the output charcoal production quality is studied. The results of the charcoal quality analysis are discussed in the paper by Kļaviņa [7].

### *2.2. Data analysis*

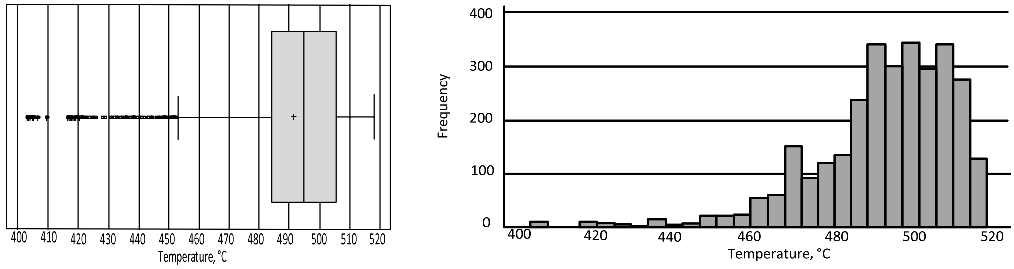
The data analysis is performed using Microsoft Excel and Statgraphics Centurion statistical data analysis tool. The data analysis is performed separately for different charcoal production process zones. First, the drying zone is analyzed. The characteristic temperatures of this zone can be used in order to estimate the amount of energy spent for the input biomass drying. The temperature measurements T1 and T2 (see Fig. 1) describe this part of the process. Likewise the analysis of the cooling zone is performed, analyzing the temperature data T3 and T4 (see Fig. 1). In this case the temperatures can be used to estimate the heat emitted from the cooling zone, and potentially utilized. The stability of the carbonization temperatures (T6 and T7) during the coal production process is analyzed.

## 3. Results and Discussion

### *3.1. Drying zone*

During the experiments enough data was collected in order to perform a statistical analysis. Flue gas input temperature T2, and effluent temperature T1, and temperature difference T2 – T1 analysis is shown in the following tables and figures. Frequency tabulation is made by dividing the measured range of T2 into equal width intervals, and counting the number of data values in each of the intervals. Box-and-Whisker plot is also created for these data.

The temperature T2 has 3018 measured data points, with the temperature variability from 402.85 to 518.49 °C.



(a) (b)

Fig. 2. (a) Box-and-Whisker plot for supply hot gas temperature T2; (b) Frequency histogram for hot flue gas T2.

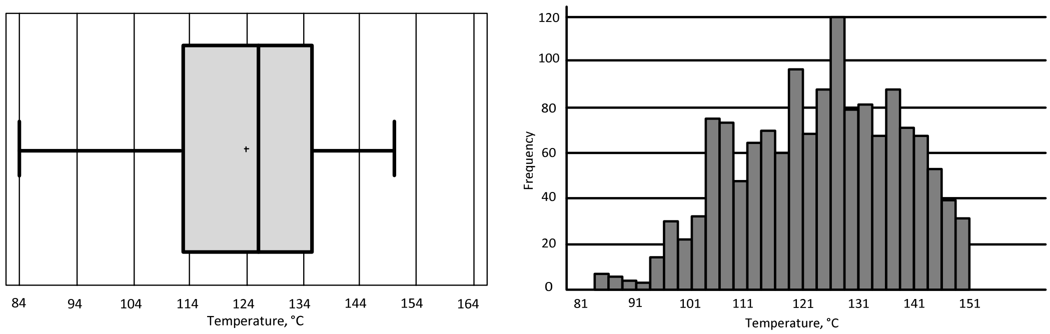
In Fig. 2 (a) it can be seen that 50 % of working temperatures were between 484 °C and 506 °C. More specific values can be seen in the histogram in Fig. 2 (b). The histogram shows the number of data values in each temperature interval. This type of analysis is done because of the large amount of data within a wide temperature range. Box-and-Whisker plot describes the whole data range and the most frequent values. The most frequent temperature values, that is the 50 % of the working temperatures, are described in Table 1.

Table 1. Frequency tabulation for supply hot gas temperatures T2.

| Lower Limit, °C | Upper Limit, °C | Midpoint, °C | Frequency, °C | Relative Frequency |
|---|---|---|---|---|
| 484.3 | 488.6 | 486.4 | 238 | 7.9% |
| 488.6 | 492.9 | 490.7 | 342 | 11.3% |
| 492.9 | 497.1 | 495.0 | 301 | 10.0% |
| 497.1 | 501.4 | 499.3 | 344 | 11.4% |
| 501.4 | 505.7 | 503.6 | 293 | 9.7% |
| 505.7 | 510.0 | 507.9 | 341 | 11.3% |
| 510.0 | 514.3 | 512.1 | 275 | 9.1% |

In the analyzed temperatures T2 the mean of the most frequent temperatures is determined to be 492.0 °C, with the Standard deviation of 18.3 °C.

The same process is undergone for the temperature of the effluent syngas after the drying zone T1. The temperature T1 has 1455 measured data points, ranging from 85.4 to 150.0 °C. The results are described in Fig. 3.



(a) (b)

Fig. 3. (a) Box-and-Whisker plot for effluent pyrolysis gas temperature T1; (b) Frequency histogram for T1.

It is visible in Fig. 3 (a) and (b), that the most frequent temperature values fall in the range from 113 to 136 °C. Based on this analysis the frequency tabulation for the most frequent data falling in the 50 % margin is described in Table 2.

Table 2. Frequency tabulation for supply hot gas temperatures T1.

| Lower Limit, °C | Upper Limit, °C | Midpoint, °C | Frequency, °C | Relative Frequency, % |
|---|---|---|---|---|
| 113.5 | 116.0 | 114.8 | 70 | 4.8 |
| 116.0 | 118.5 | 117.3 | 60 | 4.1 |
| 118.5 | 121.0 | 119.8 | 97 | 6.7 |
| 121.0 | 123.5 | 122.3 | 68 | 4.7 |
| 123.5 | 126.0 | 124.8 | 88 | 6.1 |
| 126.0 | 128.5 | 127.3 | 120 | 8.3 |
| 128.5 | 131.0 | 129.8 | 79 | 5.4 |
| 131.0 | 133.5 | 132.3 | 81 | 5.6 |
| 133.5 | 136.0 | 134.8 | 67 | 4.6 |
| 136.0 | 138.5 | 137.3 | 88 | 6.1 |

In the analyzed temperatures T1 the mean of the most frequent temperatures is determined to be 123.9 °C, with the Standard deviation of 14.4 °C.

Next the Statistical analysis is performed for the temperature difference between the hot pyrolysis gas before the drying zone, and the effluent pyrolysis gas after the drying zone (T2–T1). The most frequent temperature difference, including the midpoint, is estimated, then the second most frequent temperature difference, etc.

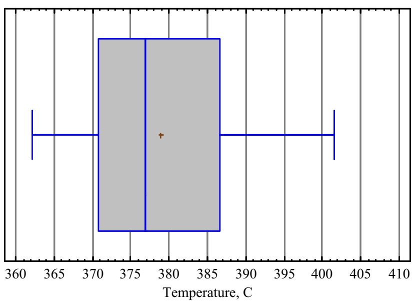
Table 3. More than 50 % frequently observed temperature difference of T2–T1.

| Temperature difference T2-T1, °C | | Relative Frequency, % | |
|---|---|---|---|
| 370.3 | | 8.0 | |
| 370.6 | | 8.7 | |
| 371.0 | | 9.0 | |
| 371.3 | | 7.6 | |
| 372.0 | | 9.8 | |
| 381.7 | | 6.5 | |
| 382.4 | | 7.3 | |
| Midpoint | 374.2 | Total | 56.9 |

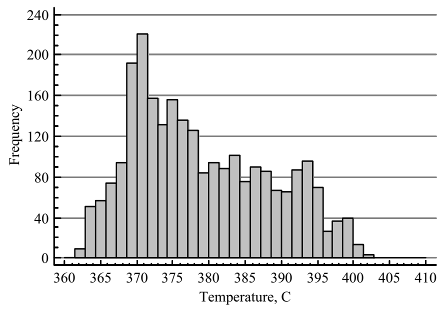
From this analysis, it can be concluded that most frequent difference or delta T2–T1 is in the range from 370.3 °C to 382.4 °C with the midpoint of 374.2 °C. The midpoint temperature difference was observed half of the measurement time. The most frequent difference 372.0 °C is advised to be selected for the calculation of the amount of energy needed for the inserted biomass drying and heating.

### *3.2. Cooling zone*

A likewise analysis is performed for the hot syngas temperature T3 and the cooled syngas temperature T4, and the temperature difference T3-T4. There are 2526 temperature T3 data points registered, with the values ranging from 362.2 to 401.6 °C. The following images in Fig. 4 describe the results of the Statistical analysis of the temperature T3.




(a)




(b)

Fig. 4 (a) Box-and-Whisker plot for the hot pyrolysis gas temperature T3; (b) Frequency histogram for T3.

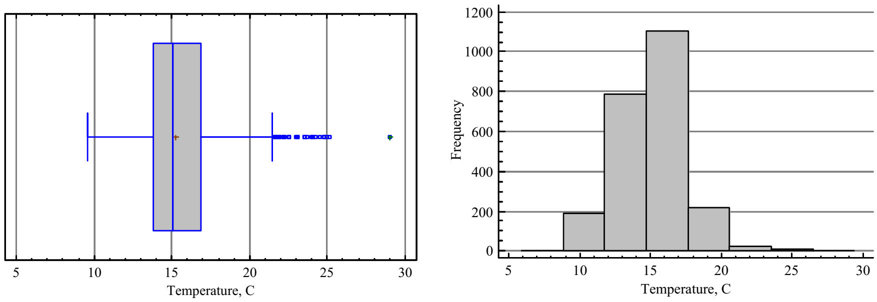
The Box-and-Whiskers plot in Fig. 4 (a) reveals that 50 % of the registered temperatures fall in the range from 371.0 to 387.0 °C. Table 4 displays the frequency tabulation addressed in the frequency histogram in Fig. 4 (b).

Table 4. Frequency tabulation for supply hot gas temperatures T4.

| Lower Limit, °C | Upper Limit, °C | Midpoint, °C | Frequency, °C | Relative Frequency, % |
|---|---|---|---|---|
| 367.1 | 368.6 | 367.9 | 94 | 3.7 |
| 368.6 | 370.0 | 369.3 | 192 | 7.6 |
| 370.0 | 371.4 | 370.7 | 221 | 8.8 |
| 371.4 | 372.9 | 372.1 | 158 | 6.3 |
| 372.9 | 374.3 | 373.6 | 132 | 5.2 |
| 374.3 | 375.7 | 375.0 | 156 | 6.2 |
| 375.7 | 377.1 | 376.4 | 136 | 5.4 |
| 377.1 | 378.6 | 377.9 | 126 | 5.0 |
| 380.0 | 381.4 | 380.7 | 94 | 3.7 |
| 382.9 | 384.3 | 383.6 | 102 | 4.0 |
| 392.9 | 394.3 | 393.6 | 96 | 3.8 |

In the analyzed temperatures T4 the mean of the most frequent temperatures is determined to be 378.9 °C, with the Standard deviation of 9.5 °C.

When analyzing T4, the cooled pyrolysis gas temperature, 2334 registered data points were selected. The selected values vary between 9.6 to 89.8 °C. The temperature value frequency distribution is visible in Fig. 5.




(a) (b)

Fig. 5. (a) Box-and-Whisker plot for the cooled pyrolysis gas temperature T4 (b) Frequency histogram for T4.

The frequency tabulation in Table 5 shows the cooled pyrolysis gas temperature T4 as described in Fig. 5 (b) with the corresponding values.

Table 5. Frequency tabulation for the cooled pyrolysis gas temperatures T4.

| Lower Limit, °C | Upper Limit, °C | Midpoint, °C | Frequency, °C | Relative Frequency, % |
|---|---|---|---|---|
| 23.5 | 26.5 | 25.0 | 10 | 0.43 |
| 20.6 | 23.5 | 22.1 | 21 | 0.90 |
| 8.8 | 11.8 | 10.3 | 193 | 8.27 |
| 17.6 | 20.6 | 19.1 | 215 | 9.21 |
| 11.8 | 14.7 | 13.2 | 785 | 33.63 |
| 14.7 | 17.6 | 16.2 | 1105 | 47.34 |

The analysis reveals the mean for the cooled pyrolysis gas temperature to be 15.2 °C with the Standard deviation of 3.1 °C.

The hot and cooled pyrolysis gas temperature difference (T3-T4) is described with the most frequent, and then the second most frequent temperature difference, the estimate includes the midpoints. The results are visible in Table 6.

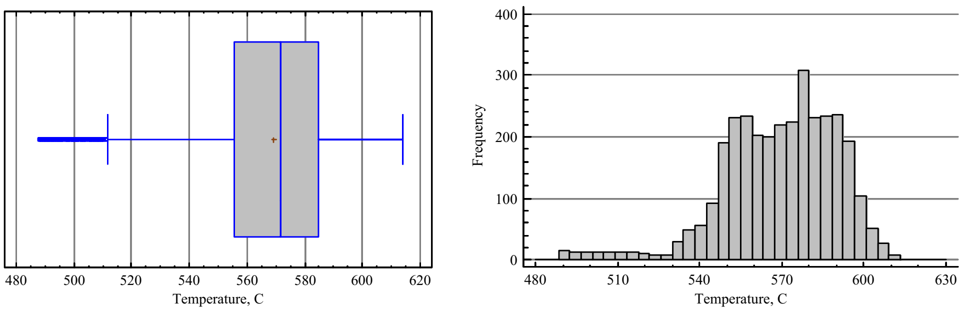
Table 6. More than 50 % frequently observed temperature difference of T3-T4.

| Temperature difference T2-T1, $^{0}$C | | Relative Frequency, % | |
|---|---|---|---|
| 348.0 | | 1.9 | |
| 348.6 | | 2.8 | |
| 353.0 | | 7.7 | |
| 354.4 | | 3.1 | |
| 354.5 | | 28.0 | |
| 356.1 | | 20.6 | |
| Midpoint | 352.4 | Total | 64.3 |

This analysis described in Table 6 indicates that the most frequent temperature T3 and T4 difference is in the interval from 348.0 to 356.1 °C, with the midpoint 353.2 °C, which can be observed more than half of the measurement time period, while the most frequent temperature difference is 354.5 °C.

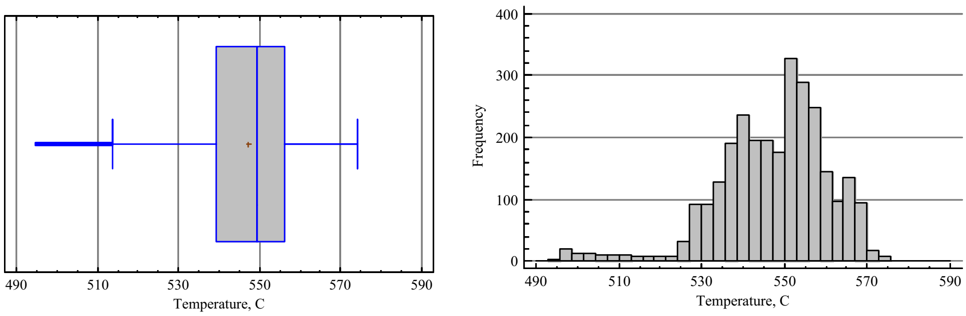
### *3.3. Carbonization zone*

The analysis of the collected Carbonization zone temperature measurement data shows that the carbonization zone temperatures in the top part (T6) range from 487.9 to 614.0 °C, and from 495.0 to 574.2 °C (T7) in the bottom part. In total 3247 data points are registered for T6, and 2814 for T7. The following images describe the results of the Statistical analysis of the temperatures T6 and T7.




(a) (b)

Fig. 6. (a) Box-and-Whisker plot for the carbonization upper part temperature T6 (b) Frequency histogram for T6.




(a) (b)

Fig. 7. (a) Box-and-Whisker plot for the carbonization upper part temperature T7 (b) Frequency histogram for T7.

As indicated in the Fig. 6 and Fig. 7, the midpoint temperature on the top of the carbonization layer (T6) is 569.0 °C, while on the bottom part of the carbonization layer the midpoint temperature (T7) is 547.2 °C, meaning that through the overall carbonization process, the temperatures are quite stable, the top and the bottom having an insignificant difference. Throughout the pyrolysis process temperature arrangement can be considered stable.

## 4. Conclusion

The study of the industrial charcoal production facility, in particular the temperatures in the three relative parts of the retort – the drying zone, carbonization zone, and the cooling zone, has returned a large amount of temperature measurement data, that is processed using the statistical analysis method. The in and out temperature of the drying zone displays the midpoint temperature difference of 374.2 °C, while the in and out temperature difference of the cooling zone has the midpoint $\Delta T$ of 354.5 °C. The carbonization layer shows a stable temperature of 547.2 to 569.0 °C. The retrieved temperature data can be used as an input in pyrolysis modelling. Further studies should be performed for other cellulosic material pyrolysis such as coniferous greenery as this is a material amply available in the Baltic States but the least utilized [8]. Additional studies should be performed in the bioeconomy field as charcoal is only one of the bioeconomy products giving higher value-added than the marketing of raw materials. For example the wooden biomass can also be used as a source of furfural [9].

## Acknowledgements

The work has been supported by the National Research Program “Energy efficient and low-carbon solutions for a secure, sustainable and climate variability reducing energy supply (LATENERGI)”.

## References

[1] Domac J, Trossero M. Industrial charcoal production. Zagreb: North-West Croatia Regional Energy Agency; 2008.
[2] Qian K, Kumar A, Zhang H, Bellmer D, Huhnke R. Recent advances in utilization of biochar. Renewable and Sustainable Energy Reviews 2015;42:1055–1064.
[3] Jahirul M, Rasul M, Chowdhury A, Ashwath N. Biofuels Production through Biomass Pyrolysis —A Technological Review. Energies 2012;5(12):4952–5001.
[4] Kļaviņa K, Kārkliņa K, Blumberga D. Charcoal production environmental performance. Agronomy Research 2015;13(2):511–519.
[5] Lambiotte A. Process of continuous carbonization. 1942.
[6] Lambiotte S. SIFIC/CISR automatic carbonization retort with capacity of 2000 tonnes of charcoal per year under continuous operation description.
[7] Kļaviņa K, Blumberga D. A comparison of different charcoal production technology outputs. Proceedings of the 10th International Scientific and Practical Conference 2015;2:137–140.
[8] Muizniece I, Blumberga D. Assessment of the Amount of Coniferous Wood Waste in the Baltic States. Energy Procedia 2015;72:57–63.
[9] Brazdauskis P, Puke M, Vedernikovs N, Kruma I. Influence of Biomass Pretreatment Process Time on Furfural Extraction from Birch Wood. Environmental and Climate Technologies 2013;11:5–11.