ELECTROSTATIC BIOMASS MIXING

Aivars Kaķītis, Imants Nulle
Institute of Mechanics, Faculty of Engineering, Latvia University of Agriculture
Aivars.Kaķītis@llu.lv, Imants.Nulle@llu.lv

Abstract. Components of mixtures have to be in required proportion and homogeneous mixed to provide good quality of briquettes or pellets. Analyzing the mixing processes several advantages for mixing biomass with an in-flow or continuous mixer were discovered. To provide better quality of the in-flow mixing process an electrical charge can be applied to the particles using corona discharge. When a sharply pointed electrode is raised to a high potential, the intense electrical field at its tip ionizes the air in its immediate vicinity. To mix particles of different bulk materials, it is necessary to give a negative electrical charge to one material, and a positive electrical charge to other material particles. The electrical charge provides mixing on a small scale, and electrostatic forces drive the process towards a perfect mixture. In this article experiments of an in-flow mixer equipped with electrodes of corona discharge are described. The methods of calibration and results of image processing of peat and sawdust mixtures using Matlab software are described in the article.

Keywords: biomass mixtures, homogeneity, image analysis, electrostatic field.

Introduction

Peat can be used as additive for manufacturing of solid biofuel, because it improves the density and durability of stalk material briquettes (pellets). The burning performance of biomass fuel using peat additive is improved also. If only wood chips or herbaceous biomass are burned, the sulphur content is low and chlorides are formed [1]. The chlorides then tend to condense on heat transfer surfaces of the steam boiler, slowing down the heat transfer and causing the risk of high temperature corrosion. If the sulphur content of the fuel is increased, e.g., by blending peat with chips or herbaceous biomass, sulphates are formed instead of chlorides and high temperature corrosion is avoided. For this reason compositions with peat for solid biofuel production are recommended.

Components of mixtures have to be in the required proportion and homogeneous mixed to provide good quality (density, durability, and burning properties) of briquettes or pellets. Analyzing the mixing processes several advantages for mixing biomass with an in-flow or continuous mixer were discovered. The machine costs of the in-flow mixing process are by 38 % lower than for the discontinuous mixing. The total operation costs for the briquetting process using an in-flow mixer are approximately 6 % less than using a cyclic mixer.

To provide better quality of the in-flow mixing process electrical charge can be applied to the particles using corona discharge. When a sharply pointed electrode is raised to a high potential, the intense electrical field at its tip ionizes [2] the air in its immediate vicinity. The ions produced move away from the electrode along the electric field lines, and this corona discharge can be used to "spray" ions (and, thus, charge) onto particles.

The uncharged particle will attract the field lines. Free ions will begin to be captured by the particle. The particle continues absorption until it has the same potential as the incoming ions. The degree of charge absorbed depends on the particle size, field strength, and time in the charge area (Fig.1 a).

When the particle has reached its saturation point of the captured ions it develops its own electric field. This new field will then cause lines of force to be pushed away from the particle. Ions can no longer reach the particle due to repulsion (Fig.1 b).

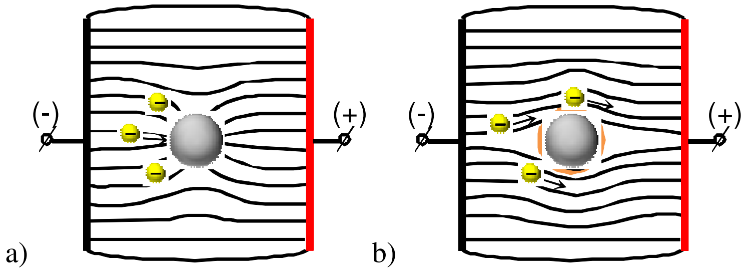


Fig. 1. **Particle in electric field**

The basic idea of this mixing device is a simple one. For example, to mix black particles with white particles, give the black particles a negative electrical charge, the white particles a positive electrical charge, and allow them to combine. Two processes will now take place concurrently: groups of like particles will repel each other and tend to spread, while unlike particles will attract each other. Once an unlike pair is combined it will remain combined as long as the particles retain their individual charges.

Experimental equipment for mixing of chopped biomass was built. The quality of mixtures made with and without electrostatic field by image analysis was estimated. Analysis through digital pictures processing was performed. The area occupied by one component particles was determined and the distance between particles was analyzed. The image processing is one of the most accurate solutions for quality assessment of a different color and tonality components mixture. An important condition for high precision of estimation is the system calibration. The methods of calibration and results of image processing of peat and sawdust mixtures using Matlab software are described in the article.

Matherials and methods

Mixing of peat and sawdust particles in an experimental equipment (in-flow mixer) was carried out (Fig. 2). The experimental equipment consists of containers 1, rotor of feeder 2 coated with a special rubber coating with knobs (highness of the knobs is 6mm), conveyer 3 and two electrodes 4 and 5. The rotation frequency of the rotor and conveyer was changed by the electromotor. The frequency of the conveyer shaft was stated using AC tachogenerator. To process impulses coming from tachogenerator PicoScope 3423 oscilloscope was used. There were two positions of electrodes. First – electrodes were placed below the conveyers (Fig. 2. a) and electrical field provided between them and second – electrodes were placed above the conveyers (Fig. 2. b) and electrical fields provided between electrodes and the corpus of the conveyer.

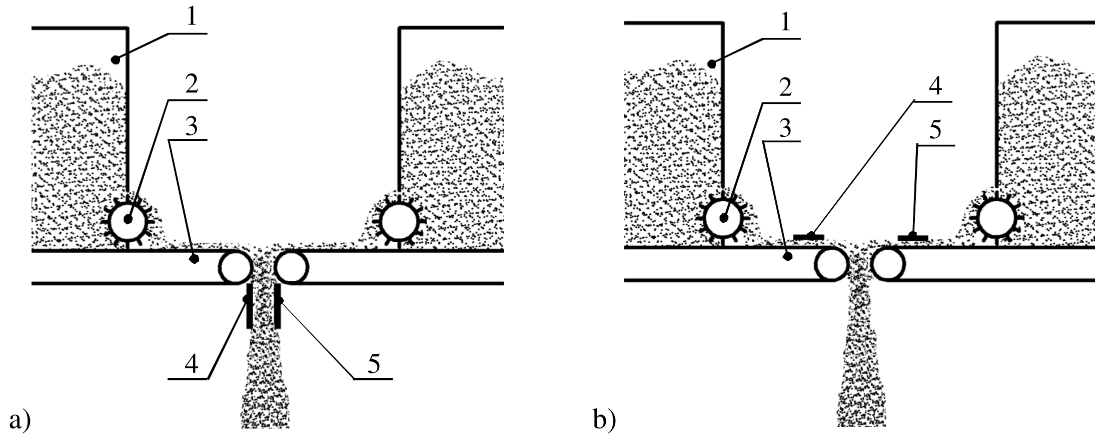


Fig. 2. **In-flow mixer:** 1 – container; 2 – rotor of feeder; 3 – conveyer; 4 – positive electrode; 5 – negative electrode

In the first case the distance between the electrodes was 30 mm. Every electrode consists of two parallel wires charged with the same voltage. The distance between the wires 27 mm. In the second case the distance between the electrodes and corpuses was 12 mm. In both cases voltage between electrodes was 10 kV.

To obtain the parameters of the in-flow mixer equipped with electrodes of corona discharge experiments with sawdust and peat were carried out. The particle size of sawdust and peat was less than 5 mm. The distribution of the particle size is shown in Fig. 3 and Fig. 4. The moisture content of the bulk material was ~12 %. The density of sawdust was ~108 kg m^{-3} but for peat ~112 kg m^{-3}.

The mixtures were scanned by a regular picture scanner and as the result one size (75 × 75 mm) and one resolution (300 dpi) pictures were obtained. To increase the contrast of the mixture components in the pictures, they were processed in one way using software *Corel-PhotoPaint* and after that saved in file type *.tif. Picture analyzing was done by software *Matlab*.

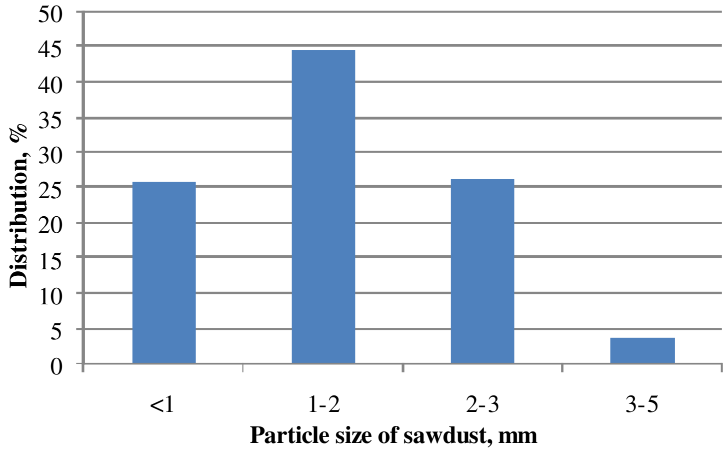


Fig.3. **Distribution of particle size of sawdust**

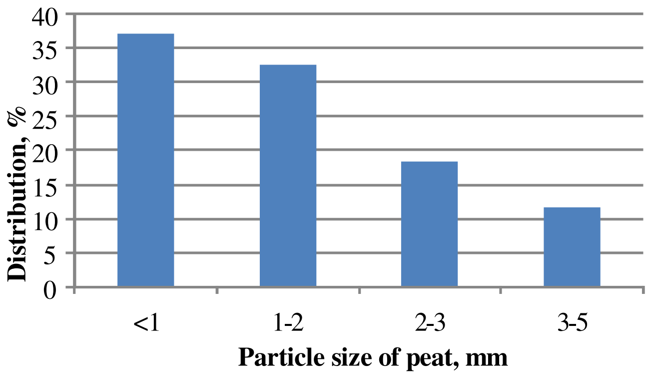


Fig.4. **Distribution of particle size of peat**

In this case, the background is the area set by darker particles, i.e., peat particles, but light particles that characterize the mixture and are further analyzed are sawdust particles. The pictures were converted to binary image where each pixel assumes one of only two discrete values: 1 or 0. Forward variable name *BW* is used referring to the binary images.

D1=bwdist(bw,'euclidean') computes the Euclidean distance transform of the *BW*. For each pixel in BW, the distance transformation assigns a number that is the distance between that pixel and the nearest nonzero pixel of *BW*. The function *bwdist* supports several distance metrics but uses the Euclidean distance metric by default. The *Euclidean distance* is the straight-line distance between two pixels. In 2-D, the *Euclidean distance* between (x_1, y_1) and (x_2, y_2) is:

$$\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \qquad (1)$$

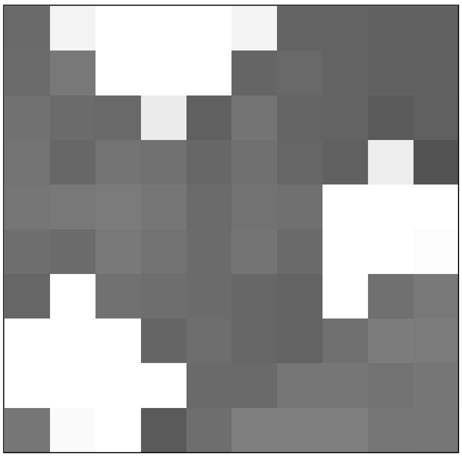
In Fig. 5 the results of Euclidean distance metric are shown. The dark field is peat between straw particles. Numbers on this field show the distance between straw particles.

The standard deviation of distance transformation for columns and rows of pixels in the picture was calculated by *Matlab*. To get the overall view of the picture (mixture), the average of the standard deviations was calculated.

The second parameter obtained from the pictures was ratio of nonzero pixel occupied area and background (whole picture) area. If this method satisfies the requirements, then the ratio of the area has to match with percentage of the component.

The visual estimation for mixtures obtained in four different processes was carried out. The first experiment was with manually mixed homogeneous samples – system calibration. The second process when mixture without high potential electrostatic field with continues mixer was obtained. The third and fourth mixing processes were with high potential electrostatic field provided. The difference in those two mixing processes was in the location of high potential electrodes – in the third case they were placed below the conveyers but in the forth case above the conveyers.

For every data point 11 samples were taken. The standard deviation of the component field ratio was calculated.



1.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	3.2
1.4	1.0	0.0	0.0	0.0	1.0	1.4	2.0	2.0	2.2
2.2	1.4	1.0	0.0	1.0	1.4	2.2	1.4	1.0	1.4
2.8	2.2	1.4	1.0	1.4	2.2	1.4	1.0	0.0	1.0
2.2	2.0	2.2	2.0	2.2	2.0	1.0	0.0	0.0	0.0
1.4	1.0	1.4	2.2	2.8	2.0	1.0	0.0	0.0	0.0
1.0	0.0	1.0	1.4	2.2	2.0	1.0	0.0	1.0	1.0
0.0	0.0	0.0	1.0	1.4	2.2	1.4	1.0	1.4	2.0
0.0	0.0	0.0	1.0	1.4	2.2	1.4	1.0	1.4	2.0
0.0	0.0	0.0	0.0	1.0	2.0	2.2	2.0	2.2	2.8
1.0	0.0	0.0	1.0	1.4	2.2	3.1	3.0	3.2	3.6

Fig. 5. **Euclidian distance transformation of BW picture**

Results and discussion

The visual estimation system calibration results for homogeneous peat and sawdust mixtures are shown in Fig. 6. In general, the results are close to the image analysis and theoretically obtained data. Deviation from the theoretical line increases when the sawdust proportion comes close to 100 % and peat proportion comes close to 100 %. It depends on the specific character of colour transform of images: conversion of sawdust picture to black and white image did not give 100 % white colour similarly with peat there was approximately 5 % difference of average values (theoretically and image analysis). This is an acceptable indicator for biomass material where homogeneity of the mixture depends on so many parameters: particle size, dispersion of particle size, particle size ratio of components, density of particles, moisture of components, and other bulk properties. High influence of data accuracy gives particle orientation, if they are thin and long, then the area of particle longitudinal section is much larger than the cross section. The accuracy of the data still can be increased by calibration of the system and precise selection of black and white levels on image transformation.

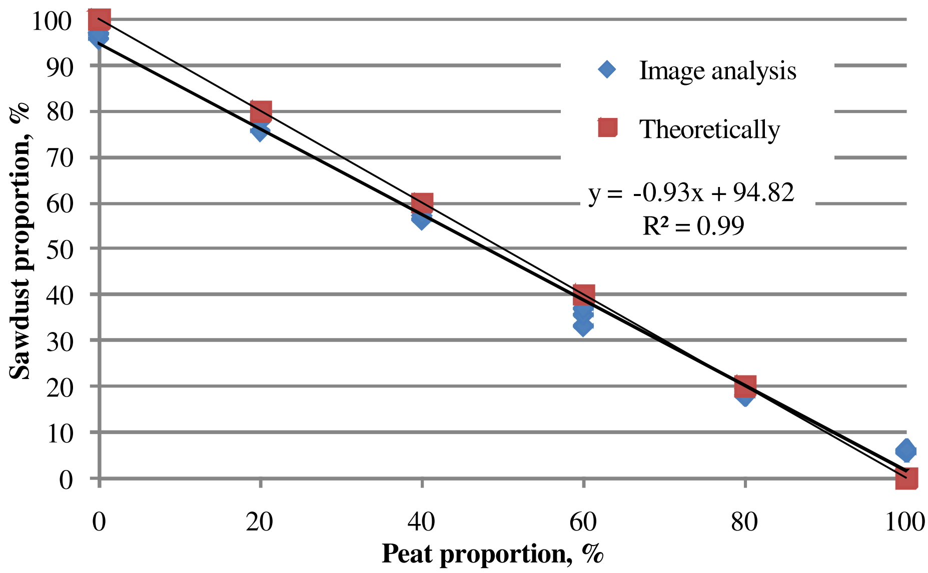


Fig. 6. **Comparison data of Image analysis and theoretical data**

Standard deviation of the distance between sawdust particles has good correlation with the increased peat proportion (Fig. 7). The coefficient of determination is 0.98. Considering that for those experiments homogeneous mixtures were used the obtained values of standard deviation can be applied for mixture quality assessment. For example, if peat proportion is 20 % than the standard deviation of Euclidean distance transform has to be approximately 0.8 for homogenous mixture.

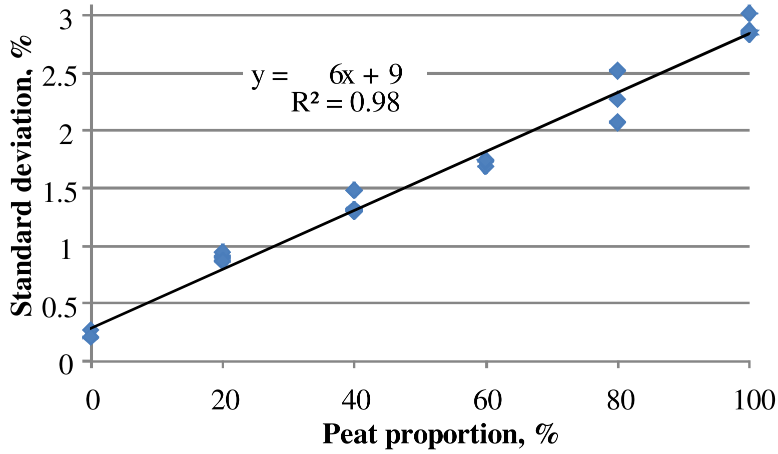


Fig. 7. **Standard deviation (pixels) of the distance between straw particles in dependence on peat proportion**

The calculated standard deviation of the components field ratio in mixtures obtained in four different mixing processes is shown in Fig. 8. This is a parameter which directly describes the homogeneity of the mixture. The standard deviation of mixtures ratio used for system calibration is below 1 %. It is because for calibration homogeneous mixtures were used. The next three data columns with continues mixer were obtained. The mixing quality without electrical field showed good results. The standard deviation of the component field ratio was 6 % that is an acceptable result for biomass mixtures. The electrical field beneath the conveyor segregated mixture and obtained standard deviation is above 12 %. Therefore, this type of mixer construction is not suggestible. Comparing with other processes above the conveyer placed electrodes improve the mixing quality and the standard deviation of the components ratio is 4 %. Improving of the mixing quality and decreasing of the standard deviation can be obtained by optimization of the electrode location and mixer design.

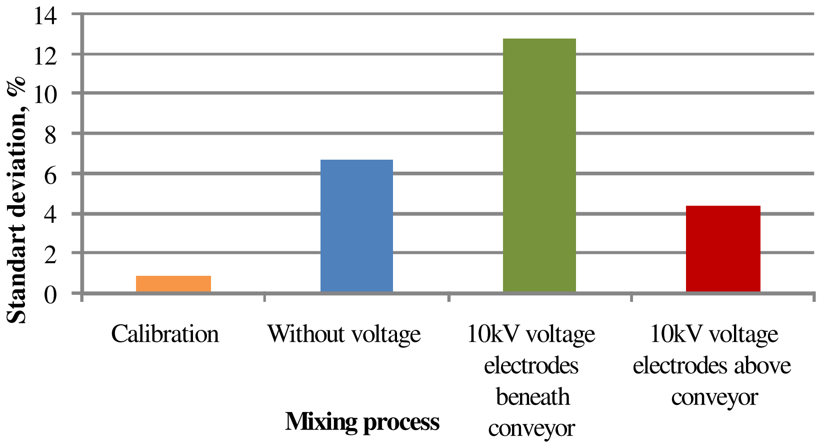


Fig. 8. **Quality of mixture in dependence of mixing process**

Conclusions

1. Inflow mixing without electrostatic field showed good mixing quality. The standard deviation of the component field ratio was 6 % that is an acceptable result for biomass mixtures.
2. Biomass charging with electrodes placed above the conveyer improves the mixing quality and the standard deviation of the components ratio decreases till 4 %.

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