Vane tester for characterization of granular biomass*

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ABSTRACT The prototype vane tester was constructed for determination of shear strength of consolidated sample of granular biomass. Measurements were conducted in 40 cm in diameter and 40 cm high cylindrical chamber. Axially, near the bottom of the chamber rotating vane tool 8 cm high and 12 cm wide was located having four blades. The normal pressure was exerted by pneumatic system with rubber air spring and the yoke. The rotating vane impeller is assumed to shear only the material in the immediate vicinity of the blades.

The measurements of torque were performed for five kinds of granular biomass used in firing and co-firing. Normal consolidation pressures in a range from 5 to 30 kPa were adopted and rotation rate ranged from 3 to 13 r/min. The value of measured torque was influenced by the kind of biomass and the consolidation pressure. No significant influence of rotation speed was observed on the value of maximum torque. Significant differences in values of maximum torque were found for different kinds of biomass. The highest value of torque, in a range from 15 to 25 Nm, was obtained in the case of pine pellet, while the lowest, not exceeding 4 Nm was that measured for oak shavings. The tester was found useful tool for characterization of granular biomass.

1. INTRODUCTION

Biomass, renewable source of energy is widely used directly as woodchips, shavings/sawdust or in form of briquettes or pellets. From physical point of view it is a granular material of different shaped particles. Knowledge of mechanical properties of granular biomass is necessary for design and efficient operation of equipment for handling, storage and processing (Zulfigar et al., 2006; Gil et al., 2013; Guo et al., 2014; Guo et al., 2014a; Guo et al., 2015 Ganesan et al., 2008; Wu et al., 2011). To assure reliable processing and efficiency of equipment exact values of material parameters are necessary (Guo et al. 2014; Adapa et al., 2009). In particular interest of bioenergy market are such characteristics as: density and parameters of strength, elasticity and flowability. Strength properties standardized in design codes (such as e.g. Eurocode 1 (2006)) are necessary for estimation of pressures of granular materials exerted on storage structures, as well as for design of installations to assure reliable flow.

Handling and processing of the biomass is relatively new branch of economy and still attempts are undertaken to elaborate new methods of characterization of these materials. Quality control is also an important task in the market of granular biomass, that decides of its commercial value. Ploof and Carson (1994) presented a comprehensive description of quality testers in use. The authors stated that tester should be easy and quickly operated with an operator with minimum skill and training. The results should be precise, repeatable and obtained in short time. The construction of such testers should be simple and compact that would allow for easy transport to proper localization.

The objective of performed project was construction of vane shear tester and examination of samples of five types of granular biomass, consolidated under pressure corresponding to this existing in storage silos used in power and heat plants.

2. MATERIAL AND METHODS

Experiments were performed on materials widely used in firing and co-firing power and heat plants in Poland: ground rapeseed straw, pine pellet, oak sawdust, oak shavings and forest woodchips. The particle size distributions and moisture contents of tested materials are presented in table 1. The materials for strength examination were chosen to represent typical kinds of granular biomass, particle size distributions and shapes of particles.

Table 1 Experimental materials data

Moisture content and particle size distributions							
Particle size mm	Ground rapeseed straw 6.5% m.c. %	Oak sawdust 5.4% m.c. %	Oak shavings 6.1% m.c. %	Forest woodchips 6% m.c. %		Pine pellets, 6mm in diameter, 4.4% m.c. %	
>5	6.3	0.0	41.9	>70	5.1	>30	20
3.2-5.0	0.4	0.0	12.9	30-70	4.1	20-30	30
2.0-3.2	3.4	3.9	23.3	16-30	4.0	10-20	40
1.6-2.0	11.4	2.1	5.7	8-16	0.4	<10	10
1.0-1.6	0.5	0.4	0.7	3-8	5.9		
0.9-1.0	36.5	12.6	11.5	<3	9.3		
0.6-0.9	3.3	9.8	2.4				
0.5-0.6	9.9	6.4	0.9				
0.4-0.5	4.5	6.5	0.5				
0.3-0.4	6.4	13.8	0.4				
0.2-0.3	6.1	14.0	0.3				
0.1-0.2	8.2	21.6	0.0				
<0.1	3.8	8.7	0.6				

The schematic of the tester is presented in figure 1. Measurements were conducted in 40 cm in diameter and 40 cm high cylindrical chamber. Inside the chamber, axially, near the bottom of the chamber rotating vane tool 8 cm high and 12 cm wide was located having four blades. The tool was driven by gear motor with variable rotation rate. The normal pressure was exerted by pneumatic system with rubber air spring and the yoke. The rotating vane impeller is assumed to shear only the material in the immediate vicinity of the blades. On the internal surface of the chamber twelve blades of dimensions equal to these of the blades of the rotating tool. The test chamber was placed on the base table and connected with the drive by claw clutch. The concept of proposed device was based on combination of the rheometer and the new system of vertical loading with compressed air filling rubber air spring and the yoke. The mass of the sample was measured with 3 load cells supporting the chamber. The actual height of the sample was measured with 3 laser sensors to determine the density of granular biomass. Torque sensor was used to measure shear load on rotating vane tool. Tests were conducted under 4 levels of consolidation pressure 5, 10, 20 and 30 kPa, for 4 rotation rates 3, 6, 9 and 13 rpm. The required consolidation pressure was realised by compressor and measured by analogue and digital manometers. The torque vs. time characteristics and other measured parameters were recorded by data acquisition system.

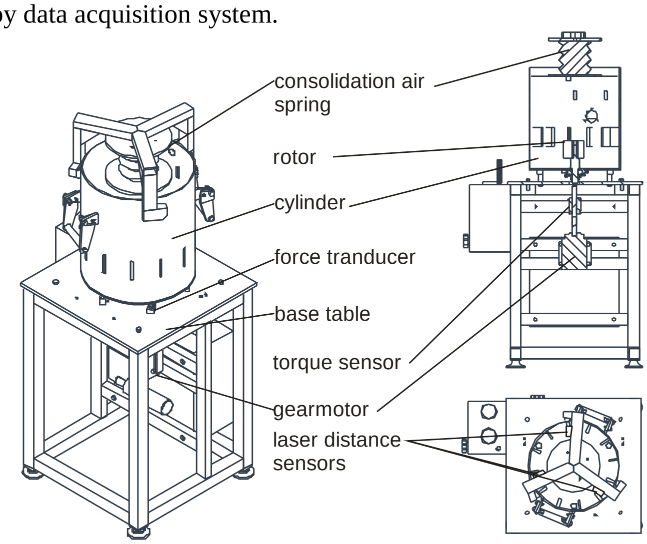

Figure 1 Experimental device

The procedure of test including filling of the chamber, consolidation with given vertical pressure, start of rotation with constant speed. After surpassing of maximum torque value the gearmotor was stopped. After a rest period of ~30 s until the torque decreased to asymptotic value, the rotation was started again and continued until the second maximum of the torque was reached. Then the sample was unloaded and the chamber was emptied. In this paper only the first torque vs time relationship is be presented.

3. RESULTS

Experimental torque vs. time relationships are presented in figure 2.

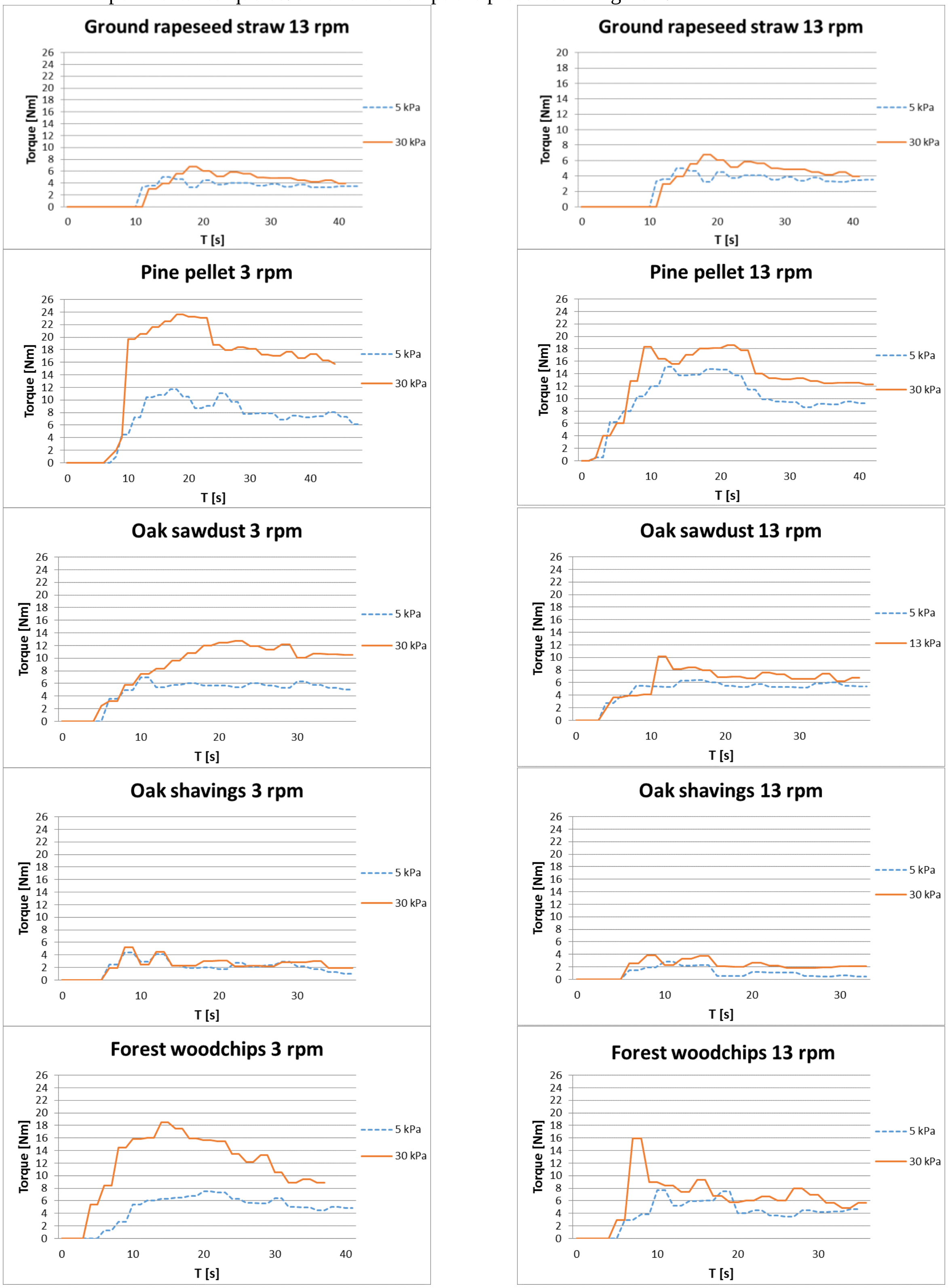

Figure 2 Experimental relationships of torque vs. time obtained for max. and min. consolidation pressures, for two rotation rates.

The relationships between time and torque in figure 2 show clear differences in behaviour of various types of biomass. Maximum values of the torque for tested materials under various consolidation pressures and rotation rates are shown in Figure 3.

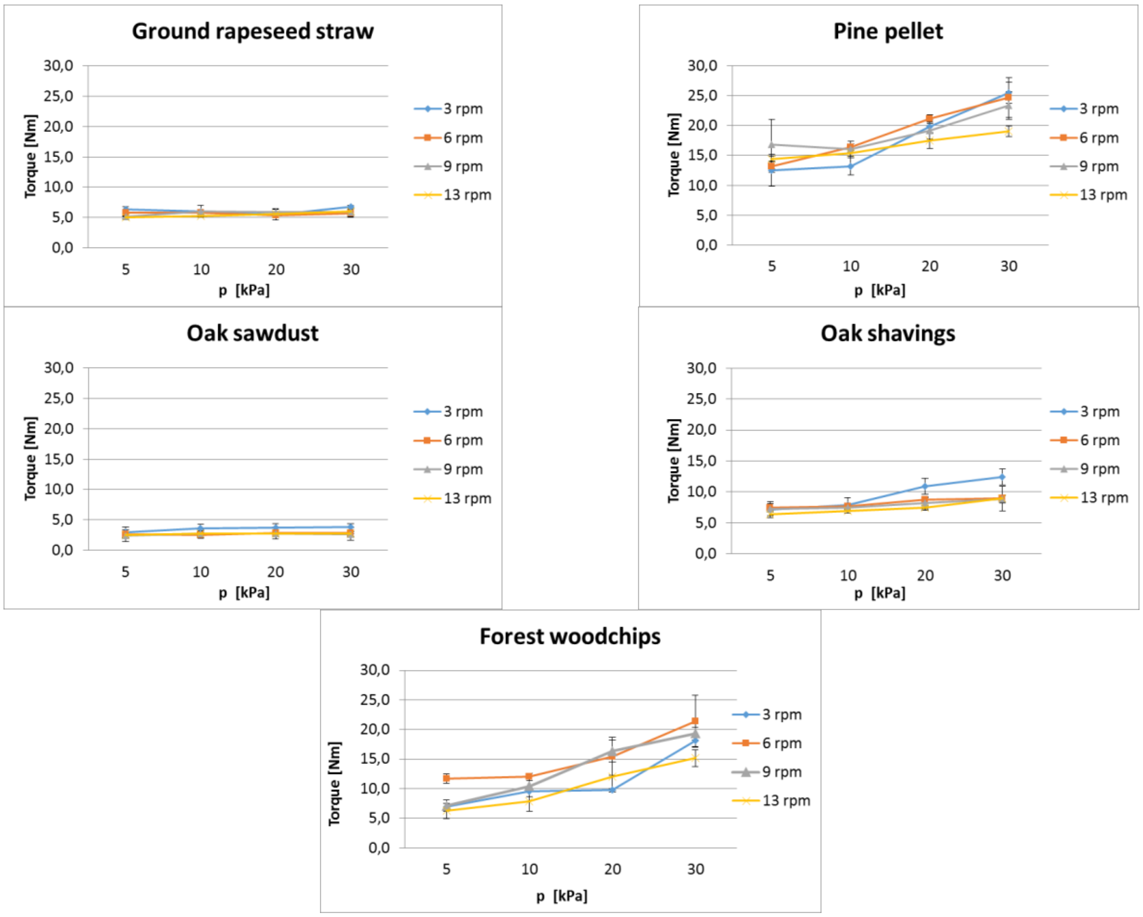

Figure 3 Torque characteristics Vs. consolidation pressure and rotation speed.

The strongest influence of consolidation pressure on the measured torque was observed in the cases of pine pellet and forest woodchips, where the torque increased up to 75% with an increase in the pressure. These two materials are the least homogeneous, with large variability in particles dimensions. In the case of pellets the lengths of particles differed in wide range. No significant differences in maximum torque for the tested consolidation pressure were noted for ground rapeseed straw and oak shavings. The maximum torque in the oak sawdust samples increased of approximately 30% with an increase in consolidation pressure from 5 to 30 kPa. No significant influence of the rotation rate on the torque values was obtained.

The highest values of maximum torque were obtained for pine pellets. The values from 15 to 25 Nm (approximately) were obtained for applied consolidation pressure. The lowest were values of the torque in the case of oak shavings found in a range from ~2.5 to ~4 Nm. Values measured for ground rapeseed straw ranged from 5 to 7 Nm and did not depend on consolidation pressure. The differences are the results of homogenity and single particle dimensions of materials. The increase in torque values in the case of woodchips, shavings and pellet is the result of single particle shape which caused interlocking during testing. The equipment used could may also be useful in estimation of loads in screw conveyors used for transport of granular biomass. The torque data determined in consolidated biomass may serve in design of transport and handling systems of such materials.

4. CONCLUSIONS

The device constructed was found efficient in determination of shear characteristics of consolidated samples of granular granular biomass.

In the case of non-homogeneous materials strong increase of torque with an increase in consolidation pressure was observed.

No significant influence of rotation rate on the maximum torque was obtained.

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